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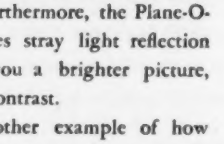

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Journal
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Devoted to Science and the Mechanic Arts

Vol. 239 JUNE, 1945 No. 6

ON THE NATURAL HISTORY OF GLOBULAR STAR CLUSTERS.*

BY

HARLOW SHAPLEY, Ph.D.,

Director of Harvard College Observatory.

In reporting on my work on globular star clusters, I shall emphasize two special researches, both bearing on the natural history of clusters.

But first I should explain what a star cluster is. There are two main kinds. The Pleiades, familiar to most of you, and the Hyades, and the Big Dipper—they are all *open* star clusters. The *globular* star clusters are best represented by the Hercules cluster, which often is shown in exhibits with any telescope. It is often shown at the Observatory of The Franklin Institute. It is a very large organization of stars; and there are about a hundred like it, belonging to our own Milky Way system. You can count the stars of a globular cluster in terms of hundreds of thousands, whereas the open clusters have only hundreds, or at the most, a thousand stars.

The stars in the open clusters are sometimes supergiant stars, while those of the globular star clusters, although very numerous, are generally only giant stars or average stars like the Sun.

The purpose of one of our investigations is to see if we can find intermediate types between the ordinary cluster of the Pleiades type, of which there are several hundred in our Milky Way, and the globular cluster, of which there are only about one hundred in our Milky Way and a few scores known in other nearby galaxies. So far, in our own galactic system we have not been able to find an intermediate type and, therefore, we cannot say that the globular clusters have originated

* A summary of the talk presented at the Medal Day Meeting at The Franklin Institute, April 18, 1945. The complete text of this paper will appear in a forthcoming issue of the *Journal of The Franklin Institute.*

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

from the open clusters or the open clusters have originated from the globular clusters. Perhaps they are not genetically associated at all.

But in the nearest of the outside galaxies, the Large Cloud of Magellan, there is a group of clusters that I cannot place in either class. They seem to be about halfway between. If we could go about fifty thousand light-years nearer that outside galaxy, we might be able to solve this particular problem, and decide whether the globular clusters there may have originated through the open clusters picking up neighboring stars and growing in population and density.

The other research bears on the direction of the development of galaxies like our Milky Way system. We are not sure which way they go—whether they go from the spheroidal galaxy to the spiral or from the spiral to the spheroidal. Some of my recent studies seem to indicate that the customary assumption that they go from the spheroidal galaxy to the spiral galaxy may not be right. It may be that the direction of evolution is from the great spirals, like our own galaxy, and like the Andromeda galaxy, toward the spheroidal form. And if the evolution is in that direction, the globular star clusters, at least the very gigantic globular star clusters, may be the end product in the evolution of galaxies.

But there are some objections to this hypothesis, and we must look into them further. Quite recently I planned some new researches which should be able to throw light on the mystery of the origin of globular star clusters. First we must help finish off the wars, then we can carry out these plans and perhaps contribute to the solution of the phylogenetic relationships among the greater stellar organizations.

NEW DEVELOPMENTS IN ELECTRON MICROSCOPY.*

BY

ROBERT G. PICARD,

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In the past twenty years, many physical and chemical phenomena, previously regarded as merely interesting effects, and devices used to demonstrate these effects, have graduated from the status of laboratory curiosities and today are of the utmost importance in industry, research, and the war effort. One can cite as examples X-rays, radio tubes, artificially radio active elements, synthetic rubber, high octane gasoline and hundreds of electronic devices.

Among these many important achievements, the electron microscope holds an outstanding position. In no sense does it supersede the ordinary microscope; it serves as a new and more powerful eye for examining the sub-microscopic world. It has been applied to diverse problems in a variety of fields of investigation. Since the development of commercial instruments, a period of only four years, a new science of electron microscopy has been created which has applications in medicine, bacteriology, chemistry, physics and metallurgy.

The development of high-power electron microscopes began about 1932. Eight years later commercial instruments were being delivered in this country, and at the present time, over 70 electron microscopes have been built here for domestic use and export. The rapid acceptance and wide applications of the instruments have led to the development of a variety of commercial models. Large versatile instruments are in use in many research laboratories, smaller desk-size models are being used to supplement these, and portable microscopes are now being developed. Hundreds of papers have appeared in scientific journals, and many popular articles have been written about electron microscopes. This activity in the field of electron microscopy can be explained on the thesis that the electron microscope is extending our knowledge in a manner both valuable and spectacular.

Much emphasis is placed on the fact that very high magnifications are obtainable with the electron microscope. The question naturally arises, "Why not build better light microscopes instead of the relatively complicated electronic equipment to accomplish the same results?" The answer to this query brings out the fundamental difference between the light and electron microscopes, a matter of resolving power, not magnification.

* Presented at a joint meeting of The Franklin Institute and the Instruments and Measurements Group of the American Institute of Electrical Engineers, January 3, 1945.

The resolving power of an optical instrument is the ability of the instrument to show detail. For a microscope, resolving power may be roughly defined as the smallest distance by which two points in an object may be separated and yet appear as two points in the image. Expressed mathematically, the definition of this smallest distance (the resolving power) is

$$d = \frac{.61\lambda}{\text{N.A.}} \tag{1}$$

where λ is the wavelength of the illumination, and N.A. is the numerical aperture of the lens system. The equation shows that the resolving power is proportional to the wavelength of the radiation used to illuminate the object. Visible light consists of radiations having wavelengths from .0004–.0008 mm. (4000–8000 A); the shorter wavelength corresponding to violet light and the longer, to red light. Details much finer than the wavelength of the illumination cannot be observed, as the tool (light) is too coarse to make the desired measurements. Therefore, the resolving power of the light microscope is limited not by the mechanical perfection of the instrument, but by the fact that light is used to examine the specimen.

The useful magnification of the light microscope is limited to about 1000 diameters if visible light is used for illumination, and about 2000 diameters if ultra-violet is used. This does not mean that photomicrographs cannot be enlarged to give over-all magnifications of a million times if desired, but such pictures will reveal no more than a 2000-magnification picture would. Points just resolved at 2000 diameters would be further separated at higher magnifications, but no additional detail would be revealed. This fact forces the microscopist to the conclusion that magnification is not the criterion which determines how deeply he can probe into the sub-microscopic world.

The electron microscope is not subject to the limitation imposed by the wavelength of light. With this instrument, specimens are irradiated with a beam of charged particles (electrons) traveling at very high velocity, and the theoretical resolution is unlimited down to sub-atomic dimensions. This resolution is determined on the basis of de Broglie's theory that every particle traveling with a velocity, v, has associated with it a wavelength, λ, determined by the equation

$$\lambda = \frac{h}{mv} \tag{2}$$

where m is the mass of the particle and h is Planck's constant ($h = 6.6 \times 10^{-27}$ erg-sec.). Experimental verification of the de Broglie relation was obtained by Davisson and Germer in 1927.[1]

[1] C. Davisson and L. H. Germer, *Phys. Rev.*, **30**, p. 707 (1927).

In terms of the voltage, V, used to accelerate the electrons, the de Broglie relation becomes

$$\lambda = \sqrt{\frac{150}{V}}\,(1 - 0.5 \times 10^{-6}V) \quad \text{Angstrom units.} \qquad (3)$$

The expression in the parentheses is a relativity correction which becomes more important as the electron velocity increases. On the basis of this theory, the wavelength associated with the electrons accelerated in the electron microscope is about .05 A, one hundred thousand times smaller than the wavelengths of visible light. From equation (1) it might be concluded that a hundred-thousandfold improvement in resolution over the light microscope would be possible; however, the aberrations inherent in present day electron optical systems make it necessary to use numerical apertures about 1000 times smaller than are used in light microscopes. In spite of this limitation, a hundredfold gain in resolving power over the light microscope has been accomplished, making possible useful magnifications of 100,000 diameters.

The beam of charged particles is focused by electric or magnetic fields in a manner analogous to the focusing action of a glass lens on light. By reason of the analogy, the charged plates or magnets giving rise to the focusing fields are called electric and magnetic lenses. The electrons which irradiate the specimen and form the magnified image are scattered and stopped by the air in a fraction of an inch; so, in order to permit the electrons to reach the specimen and then form an image, the entire instrument must be highly evacuated; in fact, it is simply a vacuum tube with means supplied to generate, accelerate, and focus electrons.

The modern high-power electron microscope physically is a vacuum tube but optically is a compound microscope, and has an optical system exactly similar to that of the familiar chemical or medical microscope (Fig. 1). Two commercial instruments now produced in this country are shown in Figures 2 and 3.[2] These instruments represent the result of continual improvement and simplification based on research and the results of four years experience in the field by many operators.

The original high magnification electron microscopes demonstrated the possibilities of the instruments, but before these potentialities could be realized in general practice, it was necessary to incorporate all the optical precision into equipment which was simple to operate, relatively compact, and easy to align and service.

One of the outstanding innovations in electron microscope design was the use of a power supply which developed high d-c voltages (50,000

[2] For detailed description of the instruments see P. C. Smith and R. G. Picard, *Radio News*, **32**, pp. 41 ff. (Nov., 1944).

volts and more) from radio frequencies. The high voltage is required to accelerate the electrons to such high speeds that they will penetrate specimens without undergoing appreciable energy losses in the specimen. A power supply to develop 50 kv. d-c from ordinary power lines (115 volt, 60-cycle a-c) requires filtering components (condensers and coils) of large physical dimensions. However, if the power is produced at radio

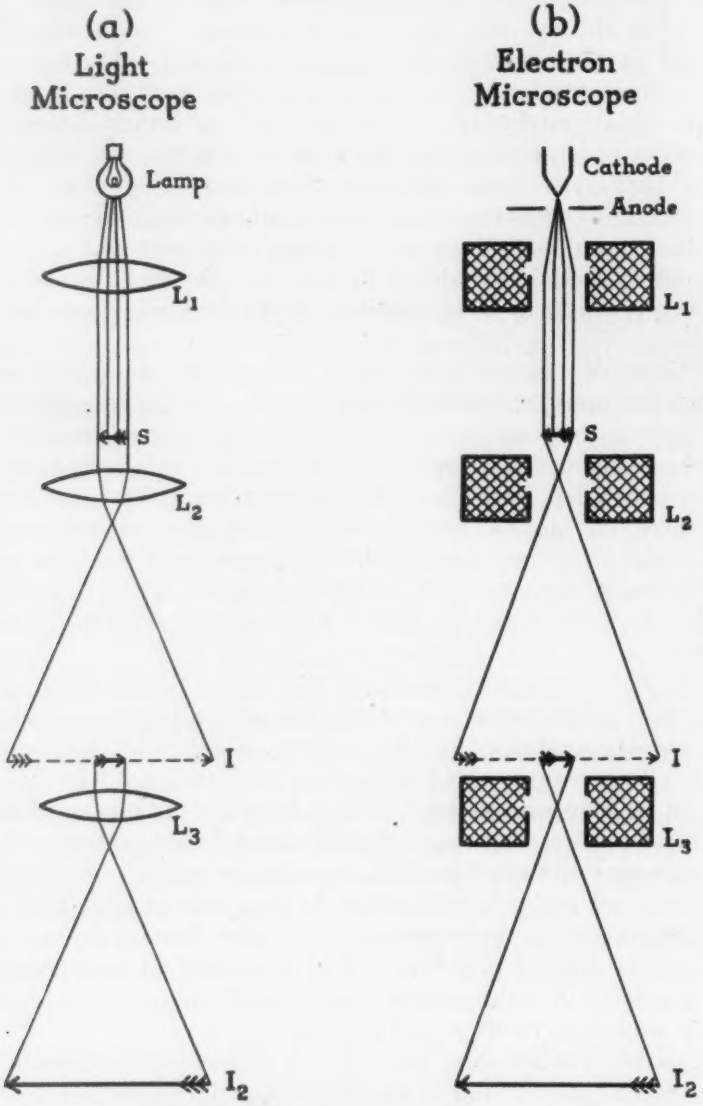

FIG. 1. Optical analogy between light and electron microscopes. L_1, substage condenser; L_2, objective; L_3, eyepiece or projection lens; S, specimen.

frequencies, the size of components is reduced, shielding is immensely simplified, and the high voltage can be easily developed in a high-Q resonant circuit. The high voltage unit used in the large electron microscopes is shown in Figure 4. This unit operates in air and generates 50,000 volts. It is regulated to maintain its voltage to ± 1

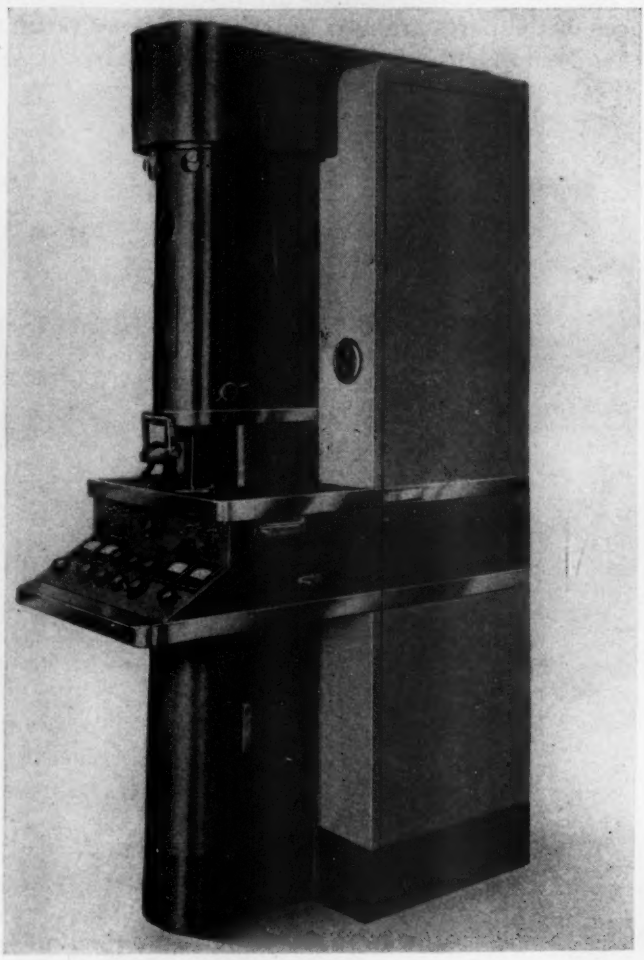

FIG. 2. Universal Electron Microscope.

volt. Such regulation is used to minimize chromatic aberration, as variations in the accelerating voltage vary the wavelength of the electrons, and thus produce a heterochromatic beam which limits resolving power.

In order to permit accurate alignment of the electron lenses and facilitate cleaning of the optical system, it is necessary that the micro-

scope column be demountable. Since the instrument must operate with a high vacuum, dependable seals must be used between sections of the column. Special synthetic rubber gaskets have been developed which make an excellent seal between parts. To assure that the correct pressure is always applied to the gaskets, the instrument has been designed so that all gasketed sections are forced together until the two metal surfaces of the parts are in contact. Whenever possible, atmospheric pressure is used to advantage for holding parts together, thus

FIG. 3. Console Electron Microscope.

reducing the number of bolts and clamps to a minimum and permitting rapid dismantling and assembly of the instrument.

While the instrument is in operation it is necessary to move the specimen stage in order to explore the specimen. After a field has been chosen to be photographed, the photographic plate must be moved, and, in the Universal Microscope, the viewing screen must be lifted. These motions are transmitted into the vacuum chamber through special rubber grommets lubricated with an oil having an extremely low vapor pressure. The grommets make a vacuum tight seal that rarely requires attention.

The pumping cycle is controlled by a set of valves built into a valve block and operated by a single crank handle. A high-speed, mechanical pump and an oil diffusion pump are used to attain the operating vacuum of 10^{-4} mm. of Hg. The valving system permits the mechanical pump to evacuate the column from atmospheric pressure to about 10^{-2} mm. without pulling the air through the diffusion pump which is

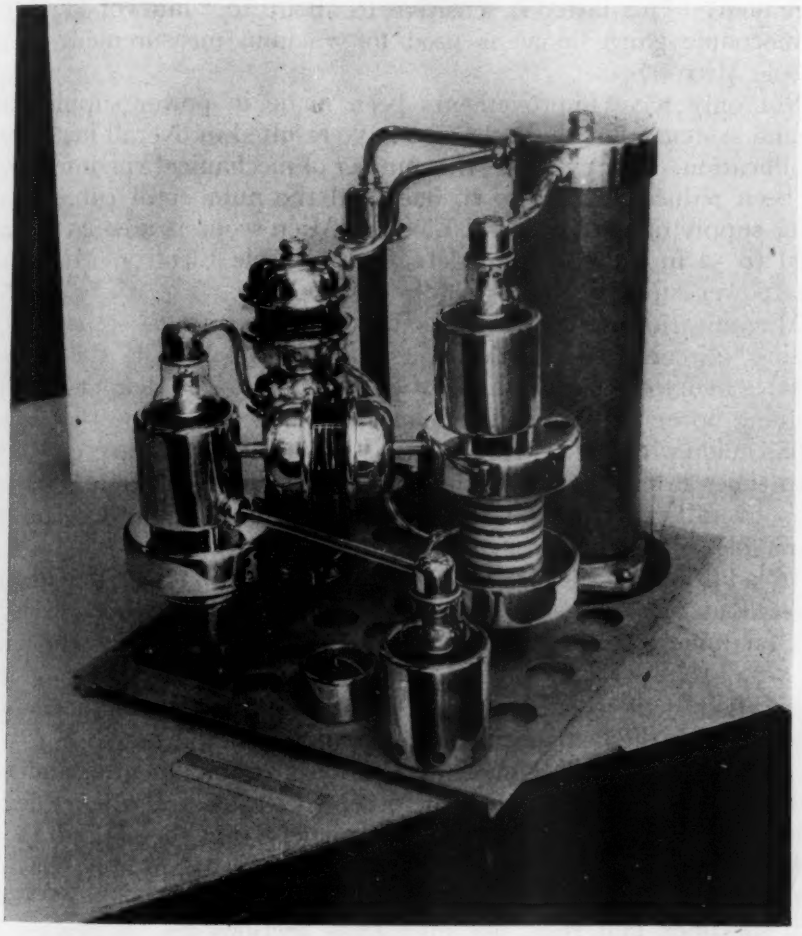

FIG. 4. High voltage unit which develops 50,000 volts in the Universal Electron Microscope.

kept hot during this "pre-pump" period. When the pressure has been reduced to about 10^{-2} mm., as read with a thermocouple gauge in the pump line, the diffusion pump is connected in series with the fore pump, and rapidly reduces the pressure in the instrument to 10^{-4} mm. of Hg. The entire pumping time from atmospheric pressure to 10^{-4} mm. is less than one minute. Since such rapid pumping is possible,

the entire instrument is filled with air whenever specimens or photographic plates are changed, and no air locks are required.

Two gauges are used continuously to read pressures in the Universal Microscope. Neither can be damaged by exposure to air while in operation, so there is no danger of burnout in case a leak should occur in the instrument. A thermocouple gauge reads pressures in the fore pump line, and a cold cathode ionization gauge reads pressure in the instrument. This latter is sensitive to about 10^{-4} mm. of Hg. The thermocouple gauge alone is used for vacuum measurement in the Console Microscope.

Not only have improvements been made in power supplies and vacuum systems, but these changes have resulted in overall instrument simplification. For example, the number of mechanical vacuum pumps has been reduced from two to one, and the number of tubes in the power supply of the Universal Electron Microscope is now 25 as compared to 52 in the earlier model. The Console Electron Microscope has a power supply which uses only 13 tubes.

Magnifications from 100 to 20,000 diameters in 40 steps may be obtained directly with the Universal Microscope, while the Console operates at fixed magnifications of either 500 or 5000 diameters. The resolving power of both instruments is of such magnitude that micrographs made with the instruments must frequently be enlarged as much as 10 times in order that all the detail shall be observable to the eye. Thus, overall useful magnifications of 50,000 to 100,000 diameters are obtainable.

In addition to the above new developments in instrumentation, tremendous advances have been made recently in other phases of electron microscopy. As in ordinary microscopy, the instrument is but a tool to observe and record information about specimens, and the preparation of the specimens and the interpretation of the information obtained with the instrument are of the utmost importance.

The problems of specimen preparation are fundamental, and have tested the ingenuity of electron microscopists to an extraordinary degree. It is necessary that specimens be extremely thin—less than 1μ and preferably about 0.1μ—in order that the electron beam may penetrate them and form a satisfactory image. Bacteria and colloids are nearly ideal specimen materials, but microtome sections are, in general, too thick to permit good images to be obtained at high magnifications. It is true that electron micrographs have been made of sectioned materials. Wedge-shaped sections have been cut which had edges thin enough to be penetrated by the electron beam, and thin spots in ordinary microtome sections have been examined. However, the thickness of the regions studied was unknown, so that calculations of density and particle distributions in the specimens could not be made.

Recently a new microtome [3] has been developed which seems to offer a solution to the problem of cutting sections less than 1μ in thickness (Fig. 5). It is known as the "cyclone knife" microtome, and uses a cutting edge traveling at several thousand feet per minute to slice the specimen. This high speed is attained by rotating the knife at 10,000 or more revolutions per minute. The sample is slowly fed into the path of the blade and is cut into uniform sections of thickness 0.25–0.1μ. This new microtome should permit the histologist and

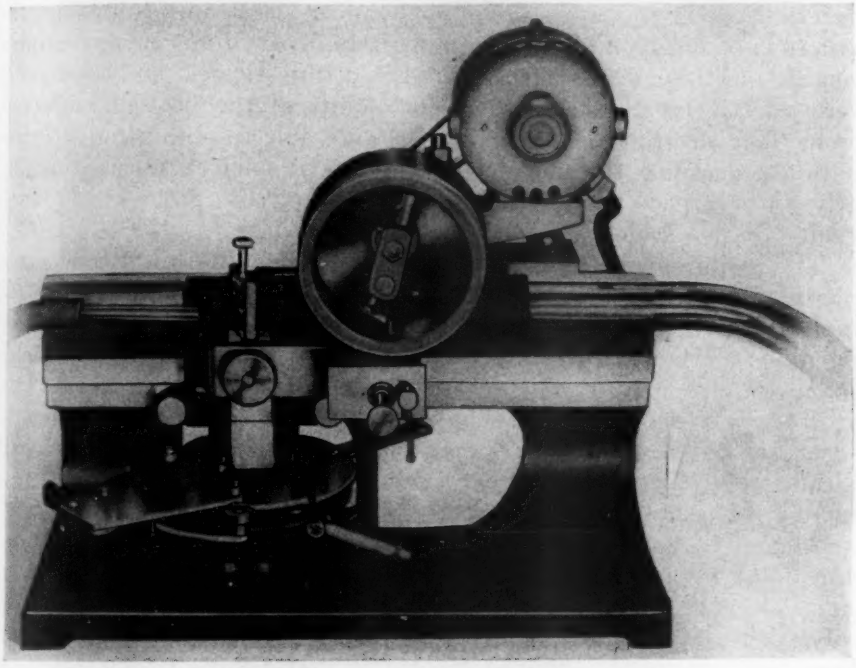

FIG. 5. High speed microtome for cutting ultra-thin sections. (Courtesy of Mr. H. C. O'Brien.)

cytologist to use the electron microscope to great advantage, and will also aid in the solution of many chemical problems arising in the electron microscopy of rubber, plastics, fibers, and other materials.

Some outstanding work has been done in the past year using stained specimens. The standard staining methods used in microscopy depend upon color to differentiate parts of a specimen, but, as the electron microscope does not use light to irradiate the specimen, such stains are of little value. In fact, in many cases, color stains obscure detail in materials in which much could be distinguished if the specimen were

[3] H. C. O'Brien and G. M. McKinley, *Science*, **98**, pp. 455–6 (1943).

unstained. This phenomenon is caused by stain being adsorbed on the specimen and being opaque to electrons.

A staining technique based upon atomic weight rather than color was developed a number of years ago. The basis of the method is the difference in scattering power for electrons exhibited by elements of high and low atomic weight. If heavy elements will attach themselves to specific parts of a specimen, that part will scatter more strongly and hence will be dark in the electron image.

An outstanding example of the application of this staining technique for electrons is the work done by Schmitt, Hall and Jakus on the structure of collagen.[4] This protein is built of atoms of low atomic weight, and these investigators found that tungstic acid and osmic acid were selectively adsorbed at specific points of the protein molecule. From their electron micrographs they were able to obtain much information concerning the molecular structure of collagen fibrils, particularly with respect to the location of hydrophyllic groups, and their results are in excellent agreement with X-ray data.

The requirement that specimens be extremely thin for electron microscopy appeared, at first, to be an insurmountable difficulty in the application of the instrument to the study of metals. However, ingenious methods of making replicas of metallic surfaces have made metallography one of the outstanding fields of application of the electron microscope.[5] Thin films of collodion or lacquers (such as Formvar) can readily be stripped from surfaces and give sufficiently faithful reproductions which are thin enough to use in the electron microscope.

About two years ago, Heidenreich [6] developed a replica technique which was so outstanding that it has become a standard procedure in many electron microscope laboratories. This technique requires that polystyrene be molded against the metal surface at high pressure. The metal is then separated from the polystyrene which bears an extremely sharp and accurate replica of the metal surface, but is too thick to use in the electron microscope. A thin film of silica is next deposited on the polystyrene replica by evaporation in high vacuum, and the polystyrene is dissolved away. Silica deposited in this manner has a high mobility over the polystyrene, and the film formed is thin, structureless, and sufficiently rigid to maintain an accurate replica of the polystyrene surface. This thin film is mounted in the instrument and examined (Fig. 6).

Replicas produced by this process have been found to show more detail than those made by other techniques. Equally important is the

[4] Papers delivered at meeting of the Electron Microscope Society of America, November, 1944.

[5] R. G. Picard and P. C. Smith, *Metals & Alloys*, **20**, pp. 636–641 (1944).

[6] R. D. Heidenreich and V. G. Peck, *J. App. Phys.*, **14**, pp. 23–29 (1943).

fact that silica replicas are not mechanically stripped from the metal surface, and hence show very little distortion.

It has been mentioned that the aberrations in electron lenses make it necessary to use small apertures in the optical system. This limitation has its bright side; namely, the electron microscope thus has a very great depth of focus. At magnifications of the order of 1000

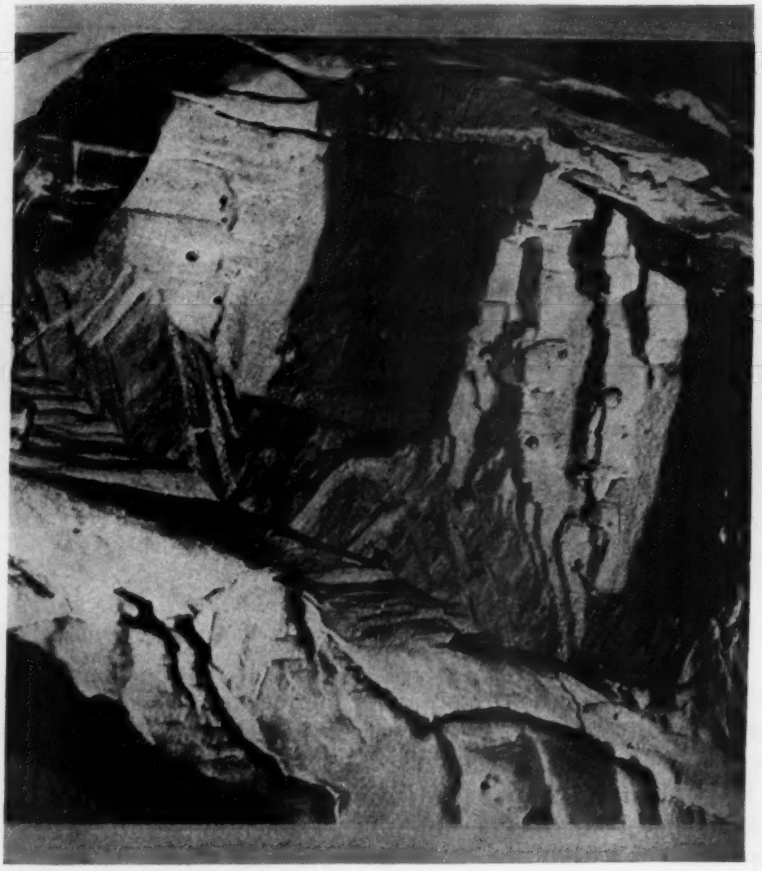

FIG. 6. Silica replica of a tiny pit etched in zinc. (Courtesy of Dow Chemical Co.)

diameters, the depth of focus of the light microscope is a small fraction of a micron; in fact, the focal plane is very nearly a true plane because such large numerical apertures must be used. The electron microscope has a depth of focus of several microns at magnifications up to 20,000 diameters, and its depth of focus at low magnifications is of the order of tens of microns. Relatively large complete structures can be observed with all details sharp throughout the image. This fact allows

the techniques of stereoscopy to be applied to the examination of specimens at high magnification.

The new electron microscopes have specimen holders which permit the specimen to be tilted with respect to the incident electron beam (Fig. 7). Thus it is possible to photograph the same field from two

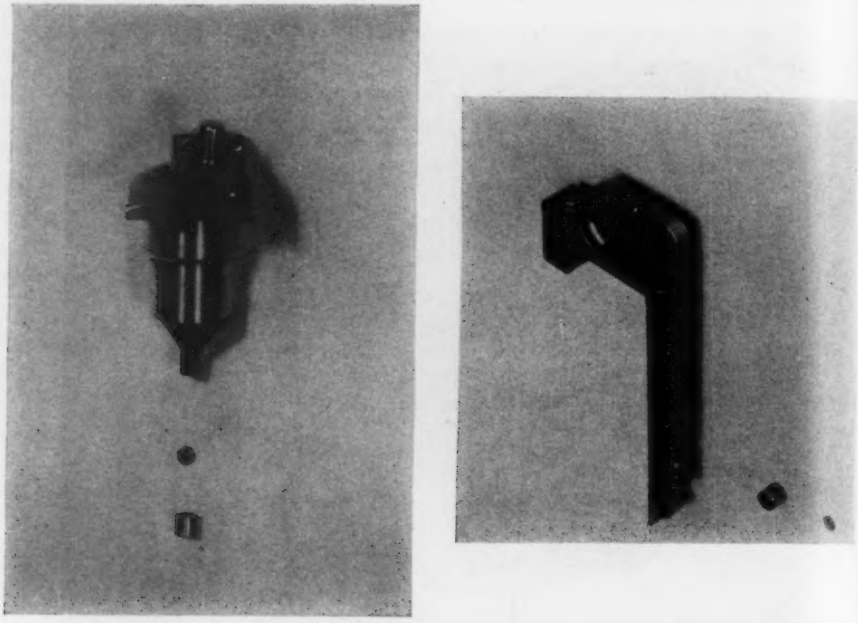

FIG. 7. Tiltable specimen holders for Universal (left) and Console Electron Microscopes.

different aspects. When this pair of micrographs is correctly oriented and viewed with a stereoscopic viewer, the field is seen in three dimensions (Fig. 8).

The Universal Electron Microscope has a special door for the specimen chamber which permits the specimen to be tilted from outside the instrument without breaking the vacuum. Thus, making a pair of stereo-micrographs is no more difficult than taking two ordinary pictures. The instrument can take 5 exposures before it is necessary to change the plate.

The Console Electron Microscope does not have a special door as the photographic plate must be changed after each exposure, and when the plate is changed, the specimen chamber door is removed and the specimen is tilted. The instrument is then evacuated and the second picture of the stereo pair is taken.

By studying the stereoscopic pair of micrographs with a contour

finder such as is used in aerial mapping,[7] it is possible to measure depth in the specimens photographed. Differences in elevation as small as a few ten-millionths of an inch (100–150 Å) are clearly resolved if the specimen is tilted as little as 8° between the two pictures.

Stereoscopy provides the best method of measuring depth in electron microscope specimens. The great depth of focus which makes stereoscopy possible prohibits the determination of the non-planar characteristics of most specimens by observing slight changes in sharpness. Determination of specimen thickness from measurements of variations in photographic density is, in general, practically impossible. The first requirement is that the specimen be homogeneous. Then the question of whether single or multiple scattering took place in the specimen must be answered. Finally, if the specimen is crystalline,

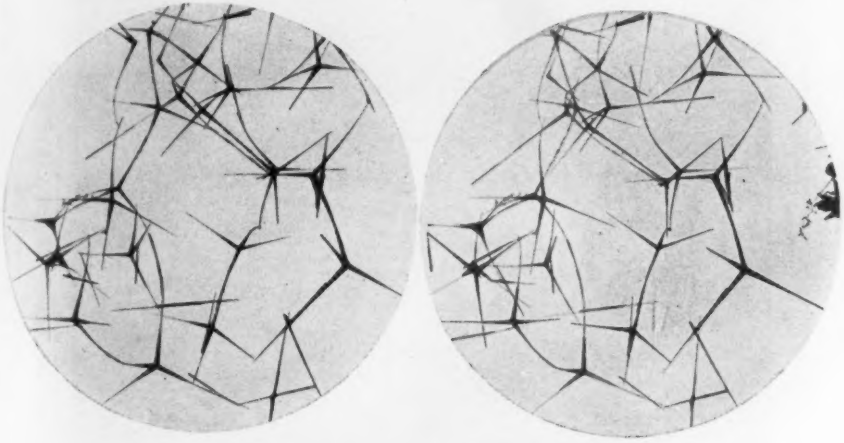

FIG. 8. Stereoscopic pair of micrographs of zinc oxide smoke.

its orientation with respect to the beam will affect the image density. In many cases study of the photographic density will allow relative thicknesses of different parts of the specimen to be estimated with reasonable accuracy, but stereoscopy is the most satisfactory method of obtaining absolute measurements of thickness.

Size, shape, and density variations of specimens are easily determined with the electron microscope, but the chemist and physicist are also interested in the atomic structure of materials. The electron microscope has the well regulated power supply, the lens system, and the photographic facilities required for an electron diffraction camera which will permit studies of atomic structure. For this reason, the Universal instrument has facilities for producing electron diffraction patterns.

To use the electron microscope as a diffraction camera, the electron

[7] R. D. Heidenreich and L. A. Matheson, *J. App. Phys.*, **15**, pp. 423–435 (1944).

beam is allowed to strike the specimen, but is not focused to produce an image of the specimen. Instead, the source of electrons is focused on the photographic plate, and the electrons diffracted by the various crystalline planes of the specimen strike the plate at different points. Each material has a characteristic pattern which serves to identify it. By working back from the pattern, it is often possible to determine the atomic structure of the specimen. Thus the diffraction adapter permits

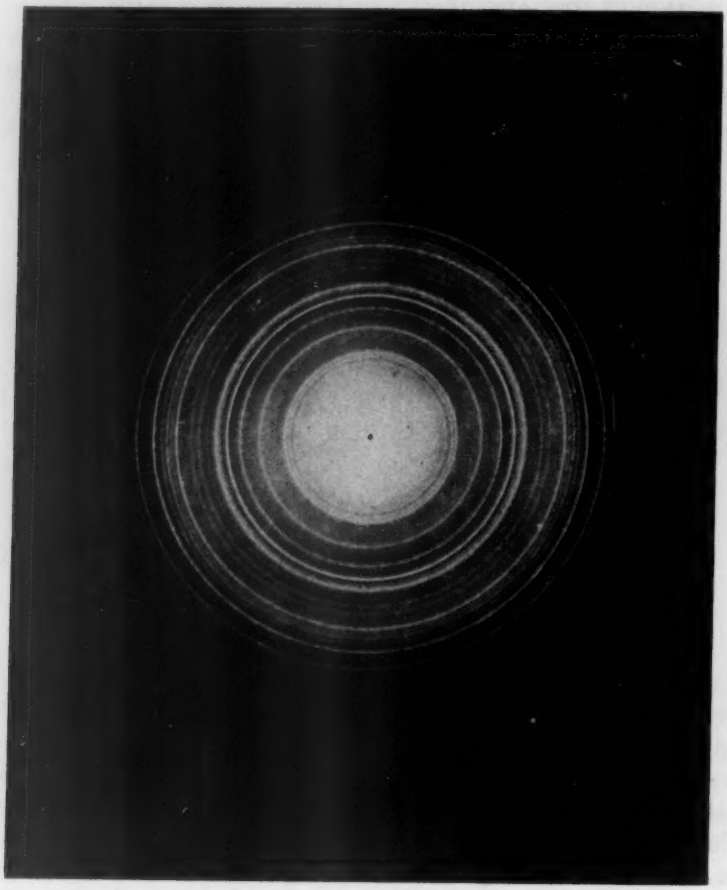

FIG. 9. Diffraction pattern (transmission) of the material shown in Figure 8.

materials to be identified by comparison of their diffraction patterns with the patterns of known materials, and also permits the detection of small amounts of impurities in samples. The percentage of each component of a mixture can also be determined with reasonable accuracy.

Diffraction patterns may be obtained by passing the electron beam through a thin film of the specimen (Fig. 9), or by allowing the beam

to strike the surface at grazing incidence (Fig. 10). This latter procedure gives rise to reflection patterns, which are actually produced by the passing of the beam through minute projections above the surface of the specimen. This is an extraordinarily powerful technique for studying the structure of surfaces, because the low penetrating power

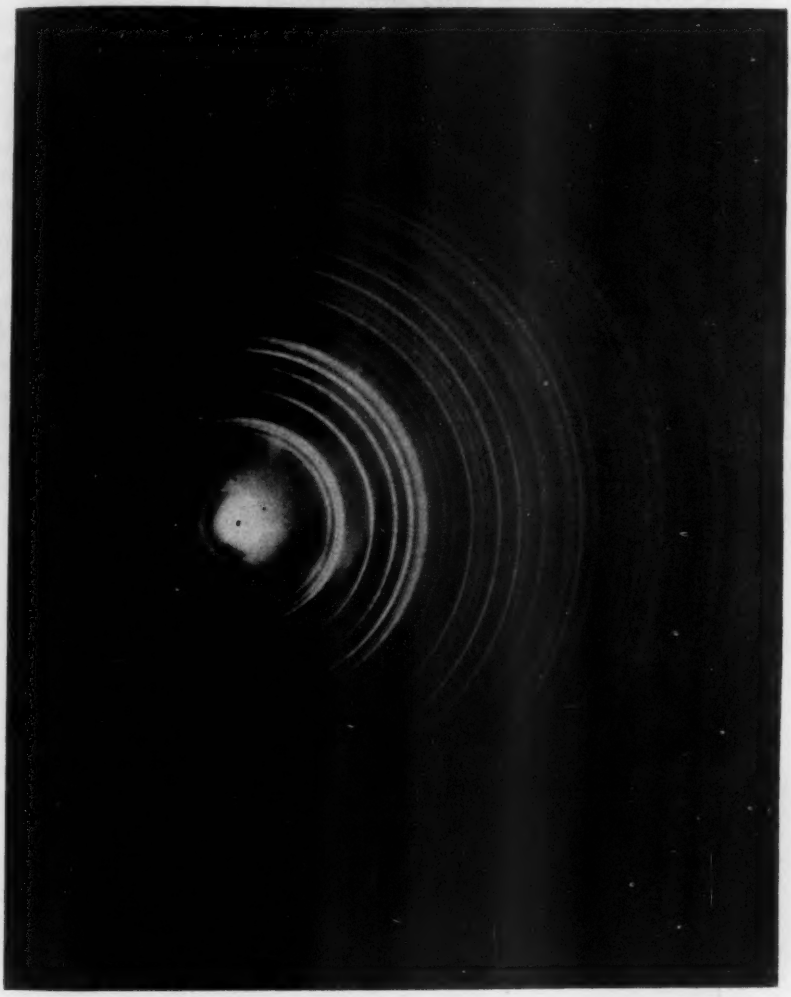

FIG. 10. Diffraction pattern from zinc oxide coated on a metal surface.

of the electron beam assures that the pattern will be due to the material on the surface and not to the backing substance.

The diffraction adapter has enhanced the value of the electron microscope by enabling the instrument to attack a wider variety of problems and to yield a new type of information.

The year 1944 marked the termination of a period in the history of electron microscopy. Over 70 instruments were in operation; a wide variety of fields of application for the microscope had been found; and the successful solution of many problems by the electron microscope had been accomplished. Today, the electron microscope has established itself as an invaluable laboratory aid, taking its place along side the light microscope, the spectroscope, X-ray and electron diffraction cameras, and a host of other instruments. Used in conjunction with these, it is contributing vastly to our knowledge of the nature of the world about us.

Now, a new phase of this infant science is beginning. No longer is the electron microscope a laboratory curiosity. The instruments are being used to investigate important research problems and they are also being widely used in production control. Much work remains to be done before the interpretation of electron micrographs can be put on as reliable a basis as the interpretation of light microscope images. However, the development of new and improved instruments, new auxiliary equipment such as the high speed microtome, and new techniques of specimen preparation, coupled with the background that only time and experience can supply, will maintain the rapid pace that has been set in the early stages of electron microscopy.

METALS AND FUELS: THE WORLD HAS ENOUGH!

BY

A. B. PARSONS,

Secretary, American Institute of Mining and Metallurgical Engineers.

I.

Today, many students of world mineral resources are expressing alarm over the rapid depletion of ore bodies and other natural deposits that yield vital metals and mineral fuels. They foresee an acute shortage in 25 or 30 years; and this opinion is voiced by writers in newspapers and magazines to such an extent that the intelligently curious layman is becoming disturbed. He reads that the huge and rich iron-ore deposits of the Lake Superior region are being exhausted rapidly; that, with the exception of Texas, all of the leading oil-producing states have passed the peak of potential production. The persistent discussion in the press of the "shortage" of petroleum and gasoline, of steel and copper, of nickel and chromium (albeit caused by war demands) accentuates this apprehension. However, the notion that the world is going to "run-out" of any essential mineral can be refuted. It overlooks significant facts as to the composition of the earth's crust; it ignores the lessons of experience; and it underestimates the imaginative ingenuity and the practical resourcefulness of scientists, of technologists, and of engineers.

Minerals, of course, differ from vegetal and animal raw materials in being "one-crop" commodities. It is true that the geologic processes by which minerals are deposited in the ground are operative today; but the cycle of these processes covers millions of years so that, from a practical standpoint, there is no current replenishment of supply. Within limits, metals can be and are salvaged for repeated use; but fuels, when once burned, are gone. However, neither can be grown nor reproduced as can rubber or timber, jute or cotton, wool or leather.

II.

Reflecting the pessimistic view regarding world mineral supplies is a recent article by Henry Cabot Lodge, Jr., former Senator from Massachusetts. He stresses the rapid depletion of mineral deposits of relatively high grade, such as are being exploited in the United States today. Based on the wartime rate of consumption and present technologic methods he gives the following "life of known reserves" in the United States:

* Presented at the Annual Dinner Meeting of the Philadelphia Section of the American Institute of Mining and Metallurgical Engineers on January 31, 1945.

Bauxite (Aluminum)	3 years	Zinc	5 years
Tungsten	5 years	Copper	10 years
Mercury	5 years	Petroleum	15 years
Lead	5 years	Iron Ore	20 years

Bearing in mind the basic premise that he is referring to relatively rich deposits, and that the current rates of consumption are abnormally high, Senator Lodge's data and statements are reasonably accurate. Although he refers only to ore deposits and oil fields situated in the United States, he might have included the entire world without changing the picture except in detail and in degree. Normally, the United States consumes roughly half of the world's output of industrial minerals; but, on the other hand, with the possible exception of Russia, it is the most richly endowed with mineral resources. With respect to some important minerals, various foreign countries have extremely large proved resources. Examples are copper in Rhodesia and Chile, manganese in Russia and India, iron ore in Brazil and Sweden, and petroleum in Venezuela, Iran, Iraq, and Arabia. In some regions, heretofore only partly prospected, highly productive new deposits doubtless will be found. However, after making every reasonable allowance, it is fair to say that Senator Lodge's data qualitatively, though not quantitatively, reflect an all-inclusive world situation. A single exception is petroleum, of which a supply is likely to be developed to last for 100 years or more. Taking a global view, six other important metals—namely, tin, nickel, chromium, vanadium, manganese, and molybdenum—might be added to those listed by the Senator. Even if some of his estimates of productive life were doubled or tripled, the outlook would would be gloomy indeed if his data told the whole story.

III.

The primary physical fact on which is predicated the adequacy of world mineral supplies is the availability in the crust of the earth of tremendous quantities of four minerals—namely, coal, iron, aluminum, and magnesium. The "crust" may be defined as a layer ten miles thick, including the hydrosphere (the ocean) and the lithosphere (the land). It is assumed that man eventually will gain access, to whatever extent may be necessary, to the minerals in this shell. Already he has drilled oil wells to a vertical depth of almost three miles.

In the United States there are estimated to be at least three *trillion* tons of mineable coal; and, roughly, twice that quantity is calculated, conservatively, for the rest of the world. This should be enough to meet all requirements of mankind for 4,000 years. Incidentally, before the supply is exhausted, ways may be devised for obtaining needed energy by cracking the atom or drawing directly on the sun itself.

Data in the accompanying table show percentages of sundry elements present in the earth's crust. They do not purport to be more

than conjectures; but they are rational conjectures, made, for the most part, by F. W. Clarke, of the U. S. Geological Survey, and are reasonably accurate. In addition to the more familiar metals, the table contains a number, like molybdenum and beryllium, that had negligible industrial value until a few years ago; but that now are important alloying elements. Also, there are some that today are laboratory curiosities. Concerning the properties and practical utility of these "new" metals little is known; but metallurgists are rapidly unlocking their secrets. At any time, they may take the place of some of the metals in common use today; or they may become active partners with them.

Content of the "Crust" of the Earth.
Including the Lithosphere and the Hydrosphere.
Percentage of Sundry Elements.

Silicon	27.720	Tungsten	0.005
Aluminum	8.130	Lithium	0.004
Iron	5.010	Zinc	0.004
Calcium	3.630	Columbium and Tantalum	0.003
Sodium	2.850	Hafnium*	0.003
Potassium	2.600	Lead	0.002
Magnesium	2.090	Cobalt	0.001
Titanium	0.630	Boron	0.001
Manganese	0.100	Beryllium	0.001
Barium	0.050	Molybdenum	0.000,1
Chromium	0.037	Arsenic	0.000,1
Zirconium	0.026	Tin	0.000,1
Nickel	0.020	Mercury	0.000,01
Vanadium	0.017	Silver	0.000,001
Gerium and Yttrium	0.015	Selenium	0.000,001
Copper	0.010	Gold*	0.000,000,1

* This is equivalent to 24,500,000,000 tons of gold.

It is true that economic production of any metal depends upon finding in the ground—or the ocean—concentrations of sufficient extent and richness to warrant exploitation. A large aggregate amount in the crust does not necessarily assure the existence of high-grade deposits. However, when and if the industrial utility of any metal becomes established, the chances are good that deposits will be found and that practical methods of exploitation will be devised. Costs may be relatively high; but, if demand is insistent, they will not be prohibitive.

Frequently, those who are apprehensive about the exhaustion of the supply of metals now in general use make this curious error (and the same applies to petroleum): they imagine that the world will wake up some morning to discover that production of an important metal had ended, totally and finally, the preceding day. On the contrary, the decline in production will be gradual; no painful disruption will occur. A long transition period will be marked by decreasing output, by a

rising price, and by restriction to use for purposes for which the metal has distinctive merit.

IV.

As long as coal is obtainable there will be no shortage of petroleum products, including fuels and lubricating oils. The proved remaining reserve of petroleum in the United States is about 22 billion barrels, or enough for 15 years at the current rate of consumption. Corresponding figures for the world are 43 billion barrels and 19 years. But petroleum geologists and geophysicists can be relied upon to find many billions of additional barrels; petroleum engineers will develop new methods for reaching greater depths, and new procedures for recovering a larger proportion of the oil permeating the rocks.

If the world were constrained to rely solely on "natural" petroleum from oil fields the supply might be adequate for a century. But long before these fields are exhausted, coal will become an important source of petroleum products. Germany already derives most of its gasoline and other liquid fuel from coal by a process of synthesis—called hydrogenation. Unquestionably hydrogenation of coal will become an important industry in the United States and in other highly industrialized countries before many years. By the time production engineers have squeezed the last drop of natural petroleum, practicably obtainable, out of the containing rocks, the need for petroleum, as such, will have vanished.

One may fairly say that the world today is in the age of steel. No valid reason exists for doubting that steel will be a dominant structural material for many decades, at least. No other country is more richly endowed with high-grade iron-ore deposits than the United States; but the reserves of such material are exhaustible. For many years, most of the important steel producing countries have been doing what the United States has now started to do—and will continue to do to an ever increasing extent: namely, mining and utilizing ores of lower grade than the 50 per cent. hematite of the great Mesabi Range. Steel companies in this country have been spoiled by the availability of rich ore; but their metallurgists are fully competent to utilize material of lower iron tenor, of which there are tremendous tonnages ready to be mined.

Low-grade iron ores abound in many countries; and the time will never come when iron cannot be obtained in whatever quantity may be desired. Mining engineers will improve methods of winning ore; mechanical processes for beneficiating low-grade ore will be perfected; furnace operation will be made more efficient. If, as seems likely, alloys of aluminum and magnesium or plastics and plywood displace iron and steel in some degree, it will not be because the latter are not to be had at reasonable cost. It will be because, on the basis of comparative price and performance in use, the former can demonstrate an overall advantage.

One group of elements, of which the relatively rich reserves are limited, are important because of their great utility for alloying with iron. By introducing small percentages of these substances, frequently in combination with one another, metallurgists produce steel having superior toughness, strength, malleability, and durability. These alloying metals include nickel, chromium, vanadium, molybdenum, and tungsten. A sixth, manganese, is used more generally; and is also more abundant than the others. Enormous deposits of low-grade manganese ore are available in foreign countries as well as in the United States. Effective methods for beneficiating these ores have been devised; and, when the need is sufficiently urgent, ample supplies of usable manganese from low-grade deposits will be ready for the steelmakers of the world.

What will happen when resources become depleted of the other ferro-alloying metals? The mining of deposits of progressively lower grade gives promise of a period of adequate supply much longer than many think. More significant, however, is the fact that each of these can be replaced, sometimes entirely and always in part, by one of the others or by one of the less commlnly known alloying elements. Among the alloying materials that the metallurgist has introduced recently are beryllium, columbium, titanium, boron, tellurium, indium, selenium, lithium, zirconium, and tantalum—elements of which the average person has scarcely heard; but that have contributed much to the steels that have gone into matériel of war.

Like iron, aluminum and magnesium are available in inexhaustible supply. Ores are widely distributed, readily accessible, and sufficiently rich to keep the cost of production within practical limits. Sea water today yields metallic magnesium at a remarkably low cost. Fifty years ago the production of aluminum was negligible; only ten years ago magnesium, as an industrial metal, was practically unknown. In 1943, the world's production of aluminum was of the order of 2,000,000 tons; and of magnesium, 500,000 tons. These figures are relatively insignificant compared with an annual world output of 175,000,000 tons of steel; and the per-ton cost is five to ten times that of low-alloy steels. However, the trend unquestionably will be to reduce this differential in cost. Moreover, the lighter materials give more utility, pound for pound; and for a great many uses, such as shapes for fabricating mobile structures, the light metals will encroach to an increasing extent on steel. Without doubt metallurgists will devise alloys of both metals that will satisfy a wide range of requirements not only as alternates to steel but to copper, lead, and zinc.

v.

This trinity—copper, lead and zinc—long have been the major nonferrous metals in point of tonnage produced and range of utility. It is true that reserves of richer ores, both in the United States and elsewhere, are being depleted with relative rapidity; and that producers

are obliged to draw upon deposits of progressively lower grade. However, no one questions the existence in many parts of the world of enormous quantities of leaner ores; and the rate of exploitation of them will hinge only upon the industrial demand for the metal in relation to price.

Consumers will learn to economize in their use of metals. Necessity—imposed by the war—has shown how metal can be conserved; how once-used metal can be recovered as a "secondary" supply satisfactory for many purposes; and how alternate materials can be substituted.

The major use for copper today is the manufacture of machines and equipment for the generation, distribution, and utilization of electric energy. The essential virtue of the metal is high electrical conductivity. For some purposes in the electrical industry aluminum can be substituted for copper; and silver is an excellent conductor of electricity. However, aluminum is bulky and silver is scarce; and for the moment copper is preeminent. Yet it is not impossible that some of the "newer" metals or new alloys may be developed for use as electrical conductors. Speculating still further, it is conceivable that, by the time copper becomes really scarce, scientists will have found ways to generate and utilize electric energy with the minimum use of metallic conductors of any kind.

In general, the long-term outlook is that alloys of iron, aluminum, and magnesium will serve many purposes for which copper, lead, and zinc are selected today. These three will be reserved for "superior" uses in which their distinctive properties are capitalized to the utmost.

Some who are most apprehensive as to the exhaustion of mineral resources give undeserved weight to increased dollar-costs of production. One writer, conceding that gasoline for motorcar fuel can be produced from coal in quantity to meet any demand, fears that the whole national economy would be irreparably dislocated if the per-gallon price of gasoline to the consumer were to become two or three times the price prevailing today. It is at least arguable that technologic progress, combined with a greatly expanded scale of production, will achieve unit costs no higher than those now current. But suppose that the gasoline cost per-mile-of-travel were doubled! No great harm would be done as long as the price increase was spread over a period of years and applied to all consumers alike. Sudden incidence and discriminatory application are the chief evils of price advances. Particularly if higher prices are the result of increases in the direct cost of production, rather than of arbitrary action of corporate monopoly, they do no great harm even though they tend to curtail the consumption of the commodity concerned.

With respect to some metals, the time may come when the production cost and, consequently, the market price may soar. It is not far-fetched to suggest that copper, for example, one hundred years hence,

may sell for $1 per pound instead of the current price of 12 cents. If the annual output, instead of 3,500,000 tons, becomes 350,000 tons, copper will be used only for those purposes for which other less costly metals or materials are distinctly inferior.

VI.

Does the foregoing argument overestimate the ability and capacity of researchers, technologists, and engineers? The best answer is the record of achievement, particularly since 1900, in developing and perfecting methods and techniques for finding and mining minerals and for processing and adapting them to industrial use. Examples abound. Early in the century, when it became necessary to exploit extremely lean porphyry copper deposits engineers devised new methods of mining the ore. Huge blocks were undercut, *in situ*, and the ore was induced to "cave" or break of its own weight, with resulting costs that were unbelievably low. As the average grade of ores of copper and lead diminished, the so-called flotation process for concentrating ores was developed. Thereby the mining of huge deposits containing less than one per cent. metal was made practical.

Progress in the art of recovering oil from underground "pools" has been phenomenal. Twenty-five years ago as little as 20 per cent. of the contained oil was recovered; today recoveries range from 50 to 80 per cent. An amazing chapter could be written on the progress in petroleum refining, culminating in the production, among other things, of aviation fuel of unbelievably high quality.

Mention already has been made of seeming miracles performed by the metallurgist and the metallurgical engineer in producing alloys that meet the most exacting demands of manufacturers. Provide the metallurgist with an unrestricted supply of iron, aluminum, and magnesium and he will manage to get along in spite of any shrinkage that may eventuate in the supply of other metals. The only other indispensable mineral raw material is coal. Of that, the supply is assured for so many centuries that the time when it becomes exhausted does not, in 1944, merit even speculative consideration.

Those who feel even mild anxiety over the threatened exhaustion of the mineral resources of the world, taken as a whole, can be reassured. Up to this minute the world has never experienced a sustained shortage of any mineral raw material. Despite all the current talk about the inadequacy of reserves of oil, iron, and other metals, there are convincing reasons for believing that, by the time supply of any of them runs low, the need for it, for one reason or another, will have ceased.

New Treatment of Posts, Poles With Chemicals in Sap Stream.—Scientists of the U. S. Department of Agriculture have developed a method by which farmers and other users of wood-lot trees can introduce chemicals into the sap stream of the wood to increase the length of service of fence posts, bean poles, garden stakes, and other utility poles.

The method is neither difficult nor expensive to use. The fresh-cut saplings are simply allowed to stand in a wooden tub or trough containing the right amount of chemical in solution for a period of about six hours, or until they have taken up the required amount of chemical. Tops of the saplings are supported by leaning them against a tree, building, or other support.

Chemicals recommended include chromated zinc chloride, zinc chloride, and copper sulfate (bluestone), of which the chromated zinc chloride is the best. These chemicals can be obtained at seed stores and other sources where farmers ordinarily buy such supplies. The chromated zinc chloride is twice as expensive as zinc chloride or copper sulfate, but it protects the wood longer, and is also less corrosive to wire staples than copper sulfate. One pound of either of the chemicals dissolved in a half gallon of water will treat one cubic foot of wood, or the equivalent of a sapling which measures about four inches at the base and is about 30 feet tall.

Best results are obtained when the saplings are treated immediately after cutting from the stumps. When it is not possible to treat them soon after cutting, or if the pitch oozes out of the soft woods, about one inch should be sawed from the cut end immediately before treating to permit the chemical solution to enter the sap stream. The lower branches may be removed for convenience in handling, but a few upper branches left attached will hasten the treating process by facilitating sap movement.

Many kinds of both hard- and soft-wood saplings or trees of a size easily handled can be treated by the sap stream method. Pine trees are more effectively protected against damage by insects and decay than are many hardwoods. The treatment is best applied during the spring and summer, particularly on bright sunny days when the sap flows most rapidly. Hardwoods can be treated only from early spring to late summer. Pine trees can be treated any time except during freezing weather. Evergreens, treated in winter, require about a day to take up the necessary amount of solution.

The method of introducing chemicals into trees and poles through the sap stream has been known to scientists for years, but until recently the method has not been practicable for use by farmers. The new technique is the result of ten years of investigations by the Bureau of Entomology and Plant Quarantine, in cooperation with the Appalachian Forest Experiment Station, U. S. Forest Service.

R. H. O.

STRESSES IN SOILS UNDER A FOUNDATION.

BY

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INTRODUCTION.

Engineers have long felt the need for a satisfactory mathematical theory for stresses in the soil under a foundation. The classical solution of Boussinesq for the semi-infinite solid loaded at its surface is sometimes used for lack of anything better, but it does not apply to soils.

Attempts have been made to modify the Boussinesq theory to adapt it to soils, the most successful of such attempts being the introduction of the so-called "concentration factor." This modification, however, applies to the vertical compressive stresses only. It has no application to shearing stresses or to horizontal compressions. Modern soil analysis recognizes the great importance of shearing stresses in determining conditions of failure and the importance of horizontal pressures has of course long been known.

In essence the problem deals with the amount of load distributed by the material in a horizontal direction by shear between the particles, as compared to that transmitted vertically downward in direct compression. In an elastic solid material the amount of this horizontal load distribution is fixed by the almost inflexible relation of the modulus of elasticity in compression, E, to the modulus of elasticity in shear, G. This is the basis of the classical elastic theory. Soils, however, behave otherwise.

A somewhat idealized soil may be considered elastic in regard to direct compression and thus have a modulus of elasticity in compression, E. It may likewise be elastic in resisting shear and thus have a modulus of elasticity in shear, G. Because of the slipping of the granules on each other the resistance to shear is much less than that in a solid and the resulting shearing deflection much greater. This means that the value of G as compared to E is much smaller in a soil than in a solid material.

This paper presents a mathematical analysis for stresses in a semi-infinite substance in which the ratio of E/G is greater than that for solids. E/G then becomes a soil constant which can be evaluated to suit tests and may vary for different soils.

In other respects the analysis conforms to the familiar assumptions of the theory of elasticity. It is developed first for problems in two dimensions and later for those in three. Some applications to particular kinds of loadings are indicated.

NOTATION.

The notation employed is generally that used by S. Timoshenko in his Engineering Societies Monograph "Theory of Elasticity."[1] An index of notation is given in Appendix I. In rectangular co-ordinates x and y are taken as horizontal and z as vertical with the positive direction downward. In the two dimensional analysis y disappears and the co-ordinates are x and z. Compression is negative and tension positive.

TWO DIMENSIONAL ANALYSIS.

In any continuous substance the fundamental relations of statics must be satisfied. These relations, that the sums of forces on any element in horizontal and vertical directions must equal zero, are:

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial T_{xz}}{\partial z} = 0, \qquad \frac{\partial \sigma_z}{\partial z} + \frac{\partial T_{xz}}{\partial x} = 0. \tag{1}$$

In these equations σ_x and σ_z are the intensities of compression in the horizontal and vertical directions and T_{xz} is the intensity of shear in the vertical plane. The weight of the soil itself is neglected. An expedient way of satisfying equations (1) is by means of the so-called stress function. If ϕ is any function of x and z, it can be readily shown that equations (1) are satisfied provided that the stresses are:

$$\sigma_x = \frac{\partial^2 \phi}{\partial z^2}, \qquad \sigma_z = \frac{\partial^2 \phi}{\partial x^2}, \qquad T_{xz} = -\frac{\partial^2 \phi}{\partial x \partial z}. \tag{2}$$

In a continuous substance it is also necessary to satisfy a relation between the strains known as the condition of compatibility.[2] This is

$$\frac{\partial^2 \epsilon_x}{\partial z^2} + \frac{\partial^2 \epsilon_z}{\partial x^2} = \frac{\partial^2 \gamma_{xz}}{\partial x \partial z}. \tag{3}$$

In equation (3) ϵ_x and ϵ_z are the unit compressive strains and γ_{xz} the unit shearing strain.

The strains and stresses are of course related by the familiar expressions:

$$\epsilon_x = \frac{1}{E}(\sigma_x - \mu\sigma_z), \qquad \epsilon_z = \frac{1}{E}(\sigma_z - \mu\sigma_x), \qquad \gamma_{xz} = \frac{1}{G} T_{xz}. \tag{4}$$

[1] McGraw-Hill Book Co., 1934.

[2] "Theory of Elasticity," by S. Timoshenko, page 22, McGraw-Hill Book Co., 1934.

In these expressions μ is Poisson's Ratio. Substituting the values of equation (4) in equation (3) there is obtained:

$$\frac{\partial^2}{E\partial z^2}(\sigma_x - \mu\sigma_z) + \frac{\partial^2}{E\partial x^2}(\sigma_z - \mu\sigma_x) = \frac{\partial^2 T_{xz}}{G\partial x\partial z}. \tag{5}$$

Then introducing the stress function as given in (2) there results

$$\frac{\partial^4\phi}{\partial x^4} + \left(\frac{E}{G} - 2\mu\right)\frac{\partial^4\phi}{\partial x^2\partial z^2} + \frac{\partial^4\phi}{\partial z^4} = 0. \tag{6}$$

To solve a two dimensional problem then, it is necessary to find a function, ϕ, which satisfies equation (6) and also the boundary conditions.

For elastic solids E, G and μ are related by the expression

$$\frac{E}{2G} = 1 + \mu. \tag{7}$$

For such materials $(E/G) - 2\mu = 2$ and all the constants of the material (E, G and μ) disappear from equation (6). In the analysis for soils equation (7) does not apply and the expression $[(E/G) - 2\mu]$ in equation (6) is greater than 2.

CONCENTRATED LOAD.

Assume a stress function in the form

$$\phi = K\left(\frac{z}{c}\log R_1 + x\tan^{-1}\frac{z}{cx}\right). \tag{8}$$

In this expression

$$R_1^2 = x^2 + \frac{z^2}{c^2}. \tag{9}$$

By differentiating successively and substituting the results in equation (6) there is obtained

$$c^4 - 2c^2\left(\frac{E}{2G} - \mu\right) + 1 = 0, \tag{10}$$

then

$$c^2 = \frac{E}{2G} - \mu \pm \sqrt{\left(\frac{E}{2G} - \mu\right)^2 - 1}. \tag{11}$$

Equation (8) then can be used as a stress function and the value of c^2 is given by equation (11). Equation (11), however, gives two values of c^2. By multiplication it can be shown that these two values are reciprocals. The plus sign in equation (11) will be used for c^2 and the minus sign will then give $1/c^2$. Using these two values the stress func-

tion becomes

$$\phi = K_1\left(\frac{z}{c}\log R_1 + x\tan^{-1}\frac{z}{cx}\right) + K_2\left(cz\log R_2 + x\tan^{-1}\frac{cz}{x}\right), \quad (12)$$

$$R_1^2 = x^2 + \frac{z^2}{c^2}, \qquad R_2^2 = x^2 + c^2z^2. \quad (13)$$

The stresses then are

$$\sigma_x = \frac{\partial^2\phi}{\partial z^2} = \frac{K_1 z}{c^3R_1^2} + \frac{K_2c^3z}{R_2^2},$$

$$\sigma_z = \frac{\partial^2\phi}{\partial x^2} = -\frac{K_1 z}{cR_1^2} - \frac{K_2cz}{R_2^2}, \quad (14)$$

$$T_{xz} = -\frac{\partial^2\phi}{\partial x\partial z} = -\frac{K_1 z}{cR_1^2} - \frac{K_2cz}{R_2^2}.$$

The constants K_1 and K_2 can be evaluated to suit the boundary conditions. If a concentrated load, P, acts at the origin of co-ordinates (see Fig. 1) the boundary conditions are:

(1) When $z = 0$, $\sigma_z = T_{xz} = 0$.

(2) For other values of z, $\int_{-\infty}^{+\infty}\sigma_z dz = -P$.

(3) When x or z approach infinity all stresses approach zero.

These conditions are fulfilled if

$$K_1 = \frac{Pc^2}{\pi(c^2-1)}, \qquad K_2 = -\frac{P}{\pi(c^2-1)}. \quad (15)$$

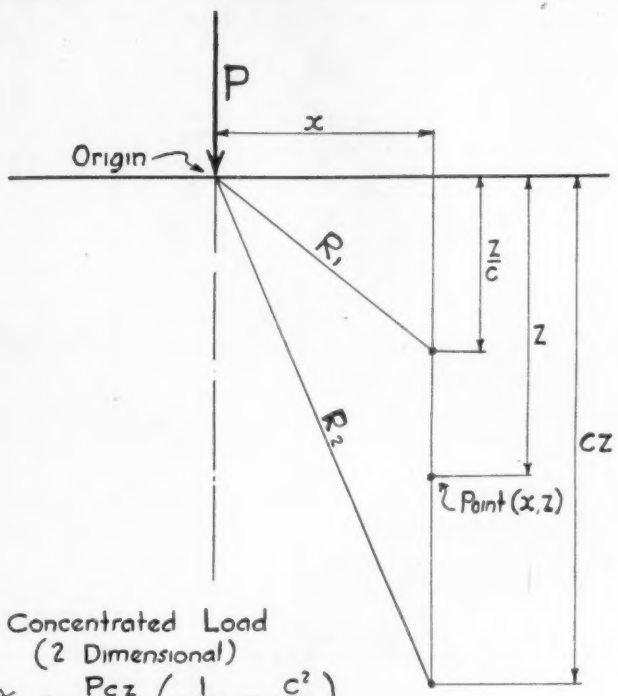
Equations (14) then become

$$\sigma_x = \frac{Pcz}{\pi(c^2-1)}\left(\frac{1}{c^2R_1^2} - \frac{c^2}{R_2^2}\right),$$

$$\sigma_z = \frac{Pcz}{\pi(c^2-1)}\left(\frac{1}{R_1^2} - \frac{1}{R_2^2}\right), \quad (16)$$

$$T_{xz} = -\frac{Pcx}{\pi(c^2-1)}\left(\frac{1}{R_1^2} - \frac{1}{R_2^2}\right).$$

Equations (16) give the stresses at any point (x, z) (see Fig. 1) in a semi-infinite solid due to a concentrated load, P, at the origin. These stresses depend on the load, the co-ordinates of the point, and one constant of the soil, c. Further discussion of the soil constant, c, will be given later.



Concentrated Load
(2 Dimensional)

$$\sigma_x = \frac{Pcz}{\pi(c^2-1)}\left(\frac{1}{c^2R_1^2} - \frac{c^2}{R_2^2}\right)$$

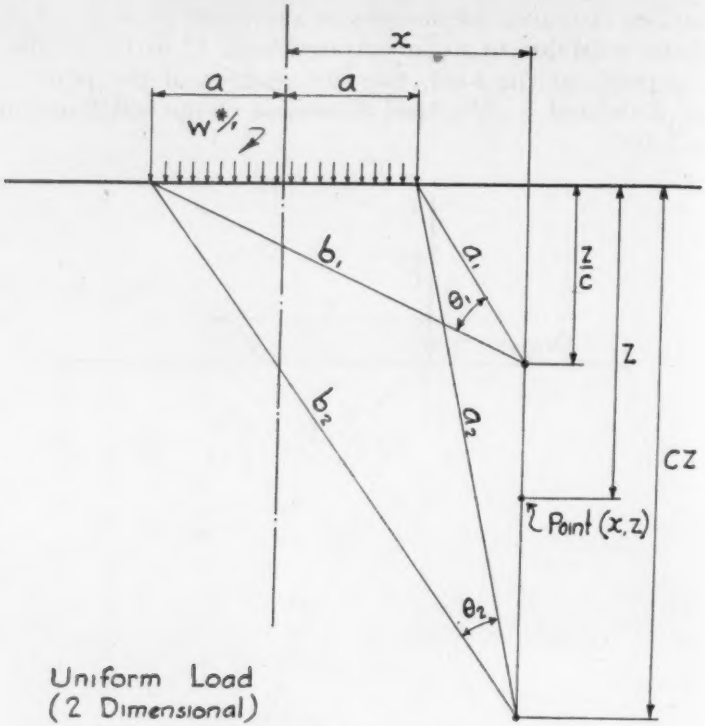
$$\sigma_z = -\frac{Pcz}{\pi(c^2-1)}\left(\frac{1}{R_1^2} - \frac{1}{R_2^2}\right)$$

$$T_{xz} = -\frac{Pcx}{\pi(c^2-1)}\left(\frac{1}{R_1^2} - \frac{1}{R_2^2}\right)$$

FIG - 1

DISTRIBUTED LOADS.

Equations (16) can readily be integrated to obtain stresses caused by uniform or uniformly varying surface loads. The resulting stresses are shown on Figs. 2 and 3. By combining stresses from various uniform or triangular loadings solutions can be obtained for stresses under earth fill dams and similar two dimensional problems.



Uniform Load
(2 Dimensional)

$$\sigma_x = \frac{w}{\pi(c^2-1)}\left(\theta_1 - c^2\theta_2\right)$$

$$\sigma_z = -\frac{w}{\pi(c^2-1)}\left(c^2\theta_1 - \theta_2\right)$$

$$T_{xz} = \frac{w\,c}{\pi(c^2-1)} \log \frac{a_1 b_2}{a_2 b_1}$$

FIG - 2

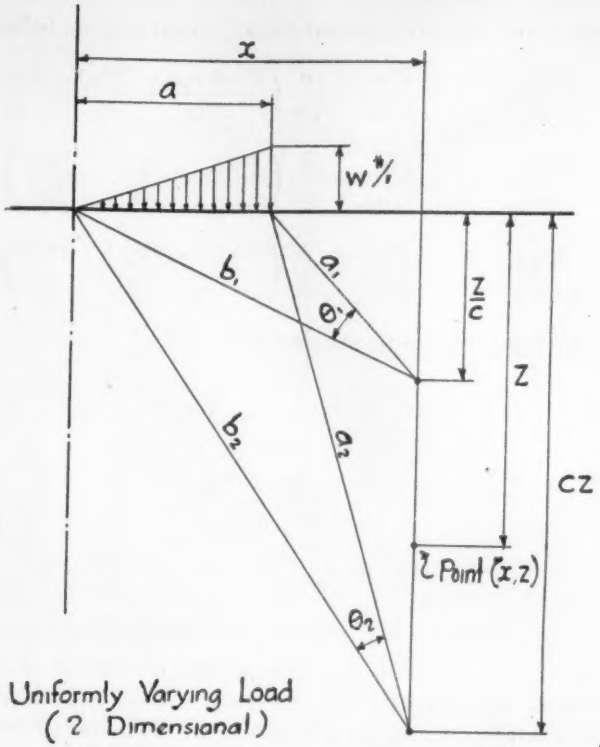
THREE DIMENSIONAL ANALYSIS.

This analysis is analogous to that for two dimensions. There are three equilibrium equations instead of two as given in equation (1)

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial T_{xy}}{\partial y} + \frac{\partial T_{xz}}{\partial z} = 0,$$

$$\frac{\partial \sigma_y}{\partial y} + \frac{\partial T_{xy}}{\partial x} + \frac{\partial T_{yz}}{\partial z} = 0, \qquad (17)$$

$$\frac{\partial \sigma_z}{\partial z} + \frac{\partial T_{xz}}{\partial x} + \frac{\partial T_{yz}}{\partial y} = 0.$$



Uniformly Varying Load
(2 Dimensional)

$$\sigma_x = \frac{wc}{a\pi(c^2-1)}\left[\frac{z}{c^2}\log\frac{a_1}{b_1} - zc^2\log\frac{a_2}{b_2} + x\left(\frac{\theta_1}{c} - \theta_2 c\right)\right]$$

$$\sigma_z = \frac{wc}{a\pi(c^2-1)}\left[z\log\frac{a_1 b_2}{b_1 a_2} + x\left(c\theta_1 - \frac{\theta_2}{c}\right)\right]$$

$$T_{xz} = -\frac{wc}{a\pi(c^2-1)}\left[x\log\frac{a_1 b_2}{b_1 a_2} + z\left(\frac{\theta_1}{c} - c\theta_2\right)\right]$$

FIG - 3

In terms of a stress function, ϕ, the stresses are

$$\sigma_x = \frac{\partial^2\phi}{\partial y^2} + k_1\frac{\partial^2\phi}{\partial z^2}, \qquad T_{xy} = -\frac{\partial^2\phi}{\partial x\partial y},$$

$$\sigma_y = \frac{\partial^2\phi}{\partial x^2} + k_1\frac{\partial^2\phi}{\partial z^2}, \qquad T_{xz} = -k_1\frac{\partial^2\phi}{\partial x\partial z}, \qquad (18)$$

$$\sigma_z = k_1\frac{\partial^2\phi}{\partial x^2} + k_1\frac{\partial^2\phi}{\partial y^2}, \qquad T_{yz} = -k_1\frac{\partial^2\phi}{\partial y\partial z}.$$

Instead of one there are six compatibility equations as follows:[3]

$$\frac{\partial^2\epsilon_x}{\partial y^2}+\frac{\partial^2\epsilon_y}{\partial x^2}=\frac{\partial^2\gamma_{xy}}{\partial x\partial y},\qquad 2\frac{\partial^2\epsilon_x}{\partial y\partial z}=\frac{\partial}{\partial x}\left(-\frac{\partial\gamma_{yz}}{\partial x}+\frac{\partial\gamma_{xz}}{\partial y}+\frac{\partial\gamma_{xy}}{\partial z}\right),$$

$$\frac{\partial^2\epsilon_y}{\partial z^2}+\frac{\partial^2\epsilon_z}{\partial y^2}=\frac{\partial^2\gamma_{yz}}{\partial y\partial z},\qquad 2\frac{\partial^2\epsilon_y}{\partial x\partial z}=\frac{\partial}{\partial y}\left(\frac{\partial\gamma_{yz}}{\partial x}-\frac{\partial\gamma_{xz}}{\partial y}+\frac{\partial\gamma_{xy}}{\partial z}\right), \tag{19}$$

$$\frac{\partial^2\epsilon_z}{\partial x^2}+\frac{\partial^2\epsilon_x}{\partial z^2}=\frac{\partial^2\gamma_{xz}}{\partial x\partial z},\qquad 2\frac{\partial^2\epsilon_z}{\partial x\partial y}=\frac{\partial}{\partial z}\left(\frac{\partial\gamma_{yz}}{\partial x}+\frac{\partial\gamma_{xz}}{\partial y}-\frac{\partial\gamma_{xy}}{\partial z}\right).$$

Equations relating stresses to strains are:

$$\epsilon_x=\frac{1}{E}[\sigma_x-\mu(\sigma_y+\sigma_z)],\qquad \gamma_{xy}=\frac{2(1+\mu)}{E}T_{xy},$$

$$\epsilon_y=\frac{1}{E}[\sigma_y-\mu(\sigma_x+\sigma_z)],\qquad \gamma_{xz}=\frac{T_{xz}}{G}, \tag{20}$$

$$\epsilon_z=\frac{1}{E}[\sigma_z-\mu(\sigma_x+\sigma_y)],\qquad \gamma_{yz}=\frac{T_{yz}}{G}.$$

It is seen in equations (20) that γ_{xy} is related to T_{xy} according to the conventional theory for solids, while in the xz and yz planes the more general relation applying to soils is used. This was done in order to obtain a satisfactory mathematical solution. The shear on the xy plane is the least critical of the stresses in practice, the ones on the vertical planes being the important ones. This assumption therefore should not adversely affect the results.

Substituting the values of the strains as given in equations (20) in equations (19) and then inserting the stress function as given in equation (18), six relations are obtained as follows:

$$\frac{\partial^2}{\partial x^2}\left(\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{k_1-\mu k_1}{1-\mu k_1}\times\frac{\partial^2\phi}{\partial z^2}\right)+\frac{\partial^2}{\partial y^2}\left(\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{k_1-\mu k_1}{1-\mu k_1}\times\frac{\partial^2\phi}{\partial z^2}\right)=0,$$

$$\frac{\partial^2}{\partial z^2}\left(\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{k_1-\mu k_1}{1-\mu k_1}\times\frac{\partial^2\phi}{\partial z^2}\right)+\frac{\partial^2}{\partial y^2}\left(\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{-1-\mu-2\mu k_1+\frac{Ek_1}{G}}{k_1-\mu}\times\frac{\partial^2\phi}{\partial z^2}\right)=0,$$

(*Equation 21 continued on next page*)

[3] "Theory of Elasticity," by S. Timoshenko, page 196, McGraw-Hill Book Co., 1934.

$$\frac{\partial^2}{\partial z^2}\left(\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{k_1-\mu k_1}{1-\mu k_1}\times\frac{\partial^2\phi}{\partial z^2}\right) \tag{21}$$

$$+\frac{\partial^2}{\partial x^2}\left(\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{-1-\mu-2\mu k_1+\frac{Ek_1}{G}}{k_1-\mu}\times\frac{\partial^2\phi}{\partial z^2}\right)=0,$$

$$\frac{\partial^2}{\partial y\partial z}\left(\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{k_1-\mu k_1}{1-\mu k_1}\times\frac{\partial^2\phi}{\partial z^2}\right)=0,$$

$$\frac{\partial^2}{\partial x\partial z}\left(\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{k_1-\mu k_1}{1-\mu k_1}\times\frac{\partial^2\phi}{\partial z^2}\right)=0,$$

$$\frac{\partial^2}{\partial x\partial y}\left(\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{-1-\mu-2\mu k_1+\frac{Ek_1}{G}}{k_1-\mu}\times\frac{\partial^2\phi}{\partial z^2}\right)=0.$$

This set of equations is analogous to equation (6) in the two dimensional analysis. The problem is to find a function, ϕ, which satisfies equations (21) and the boundary conditions.

STRESS FUNCTION.

Assume a stress function of the form

$$\phi = K\log\left(\frac{z}{c}+R_1\right). \tag{22}$$

Where

$$R_1^2 = x^2+y^2+\frac{z^2}{c^2}.$$

It can be readily shown that

$$\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+c^2\frac{\partial^2\phi}{\partial z^2}=0. \tag{23}$$

This stress function will satisfy all of equations (21) provided that

$$c^2=\frac{k_1-\mu k_1}{1-\mu k_1}=\frac{-1-\mu-2\mu k_1+(Ek_1/G)}{k_1-\mu}, \tag{24}$$

solving this

$$k_1=\frac{\frac{E}{G}\pm\sqrt{\frac{E^2}{G^2}-4\mu(1+\mu)\left(\frac{E}{\lambda}+\frac{E}{G}\right)}}{2\mu\left(\frac{E}{\lambda}+\frac{E}{G}\right)}. \tag{25}$$

$$c^2 = \frac{1-\mu}{\mu} \times \frac{\frac{E}{G} \pm \sqrt{\frac{E^2}{G^2} - 4\mu(1+\mu)\left(\frac{E}{\lambda} + \frac{E}{G}\right)}}{\frac{2E}{\lambda} + \frac{E}{G} \mp \sqrt{\frac{E^2}{G^2} - 4\mu(1+\mu)\left(\frac{E}{\lambda} + \frac{E}{G}\right)}}. \quad (26)$$

In these expressions

$$\lambda = \frac{E\mu}{(1+\mu)(1-2\mu)}. \quad (27)$$

There are then double values for k_1 and c^2. However, it can be shown that as in the two dimensional analysis, the two values of c^2 are reciprocals. For convenience we will use the upper signs for k_1 and c^2 and the lower signs for k_2 and $\frac{1}{c^2}$.

CONCENTRATED LOAD.

Computing the derivatives of equation (22) and putting these in equations (18) values of σ_z, T_{xz}, and T_{yz} can be obtained

$$\sigma_z = K_1 k_1 \frac{z}{cR_1^3} + K_2 k_2 \frac{cz}{R_2^3},$$
$$T_{xz} = K_1 k_1 \frac{x}{cR_1^3} + K_2 k_2 \frac{cx}{R_2^3}, \quad (28)$$
$$T_{yz} = K_1 k_1 \frac{y}{cR_1^3} + K_2 k_2 \frac{cy}{R_2^3}.$$

As in the two dimensional case values of K_1 and K_2 can be determined from the boundary conditions. For a concentrated load, P, located at the origin these conditions are

(1) When $z = 0$, $\sigma_z = T_{xz} = T_{yz} = 0$.

(2) For other values of z, $\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} \sigma_z dxdy = -P$.

(3) When x, y, or z approaches infinity, all stresses approach zero.

These conditions lead to values of K_1 and K_2 as follows:

$$K_1 = \frac{Pc^2}{2\pi k_1(c^2-1)}, \qquad K_2 = -\frac{P}{2\pi k_2(c^2-1)}. \quad (29)$$

By computing derivatives of equation (22) and inserting these and

the values of K_1 and K_2 in equations (18) there results:

$$\sigma_x = -\frac{Pc}{2\pi(c^2-1)}\left[c\frac{R_1^2\left(\frac{z}{c}+R_1\right)-y^2\left(\frac{z}{c}+2R_1\right)}{k_1R_1^3\left(\frac{z}{c}+R_1\right)^2}\right.$$

$$\left.-\frac{z}{c^2R_1^3}-\frac{R_2^2(cz+R_2)-y^2(cz+2R_2)}{ck_2R_2^3(cz+R_2)^2}+\frac{c^2z}{R_2^3}\right],$$

$$\sigma_y = -\frac{Pc}{2\pi(c^2-1)}\left[c\frac{R_1^2\left(\frac{z}{c}+R_1\right)-x^2\left(\frac{z}{c}+2R_1\right)}{k_1R_1^3\left(\frac{z}{c}+R_1\right)^2}\right.$$

$$\left.-\frac{z}{c^2R_1^3}-\frac{R_2^2(cz+R_2)-x^2(cz+2R_2)}{ck_2R_2^3(cz+R_2)^2}+\frac{c^2z}{R_2^3}\right], \qquad (30)$$

$$\sigma_z = -\frac{Pcz}{2\pi(c^2-1)}\left[\frac{1}{R_1^3}-\frac{1}{R_2^3}\right],$$

$$T_{xz} = -\frac{Pcx}{2\pi(c^2-1)}\left[\frac{1}{R_1^3}-\frac{1}{R_2^3}\right],$$

$$T_{yz} = -\frac{Pcy}{2\pi(c^2-1)}\left[\frac{1}{R_1^3}-\frac{1}{R_2^3}\right],$$

$$T_{xy} = -\frac{Pcxy}{2\pi(c^2-1)}\left[c\frac{\frac{z}{c}+2R_1}{k_1R_1^3\left(\frac{z}{c}+R_1\right)^2}-\frac{cz+2R_2}{ck_2R_2^3(cz+R_2)^2}\right].$$

These equations give the stresses at any point, (x, y, z) due to a concentrated load, P, at the origin. The similarity between the expressions for σ_z, T_{xz} and T_{yz} in the two and three dimensional problems is striking. These expressions involve only one soil constant, c. The expression for c, however, is not the same in the two and three dimensional analyses. The values for σ_x, σ_y and T_{xy} involve two additional soil constants k_1 and k_2.

UNIFORMLY DISTRIBUTED LOADS.

If the coordinates of a differential area on the loaded surface are x' and y', values of R_1 and R_2 are

$$R_1^2 = (x - x')^2 + (y - y')^2 + \frac{z^2}{c^2}, \qquad R_2^2 = (x - x')^2 + (y - y')^2 + c^2 z^2. \tag{31}$$

Stresses for a uniformly distributed load then take the following form:

$$\sigma_x = \frac{wc}{2\pi(c^2-1)} \int\int \left[\frac{c\partial^2 \log\left(\frac{z}{c} + R_1\right)}{k_1 \partial y^2} + \frac{c\partial^2 \log\left(\frac{z}{c} + R_1\right)}{\partial z^2} - \frac{\partial^2 \log (cz + R_2)}{ck_2 \partial y^2} - \frac{\partial^2 \log (cz + R_2)}{c\partial z^2} \right] dx'dy',$$

$$\sigma_y = \frac{wc}{2\pi(c^2-1)} \int\int \left[\frac{c\partial^2 \log\left(\frac{z}{c} + R_1\right)}{k_1 \partial x^2} + \frac{c\partial^2 \log\left(\frac{z}{c} + R_1\right)}{\partial z^2} - \frac{\partial^2 \log (cz + R_2)}{ck_2 \partial x^2} - \frac{\partial^2 \log (cz + R_2)}{c\partial z^2} \right] dx'dy',$$

$$\sigma_z = -\frac{wc}{2\pi(c^2-1)} \int\int \left[\frac{c^3\partial^2 \log\left(\frac{z}{c} + R_1\right)}{\partial z^2} - \frac{\partial^2 \log (cz + R_2)}{c^3 \partial z^2} \right] dx'dy',$$

$$T_{xy} = -\frac{wc}{2\pi(c^2-1)} \int\int \left[\frac{c\partial^2 \log\left(\frac{z}{c} + R_1\right)}{k_1 \partial x \partial y} - \frac{\partial^2 \log (cz + R_2)}{ck_2 \partial x \partial y} \right] dx'dy', \tag{32}$$

$$T_{xz} = -\frac{wc}{2\pi(c^2-1)} \int\int \left[\frac{c\partial^2 \log\left(\frac{z}{c} + R_1\right)}{\partial x \partial z} - \frac{\partial^2 \log (cz + R_2)}{c\partial x \partial z} \right] dx'dy',$$

(*Equation 32 continued on next page*)

$$T_{yz} = -\frac{wc}{2\pi(c^2-1)}\int\int\left[\frac{c\partial^2 \log\left(\frac{z}{c}+R_1\right)}{\partial y\partial z} - \frac{\partial^2 \log\,(cz+R_2)}{c\partial y\partial z}\right]dx'dy'.$$

If the loaded area is a rectangle with sides $2a$ and $2b$ and with the origin at its center (see Fig. 4) the values of these double integrals are:

$$\int_{-a}^{+a}\int_{-b}^{+b}\frac{\partial^2 \log\left(\frac{z}{c}+R_1\right)}{\partial x^2}dx'dy'$$

$$= \tan^{-1}\frac{b-y}{a-x} + \tan^{-1}\frac{b+y}{a-x} + \tan^{-1}\frac{b-y}{a+x} + \tan^{-1}\frac{b+y}{a+x} - \tan^{-1}\frac{z(b-y)}{ca_1(a-x)} - \tan^{-1}\frac{z(b-y)}{cb_1(a+x)} - \tan^{-1}\frac{z(b+y)}{cc_1(a+x)} - \tan^{-1}\frac{z(b+y)}{cd_1(a-x)},$$

$$\int_{-a}^{+a}\int_{-b}^{+b}\frac{\partial^2 \log\left(\frac{z}{c}+R_1\right)}{\partial y^2}dx'dy'$$

$$= \tan^{-1}\frac{a-x}{b-y} + \tan^{-1}\frac{a+x}{b-y} + \tan^{-1}\frac{a-x}{b+y} + \tan^{-1}\frac{a+x}{b+y} - \tan^{-1}\frac{z(a-x)}{ca_1(b-y)} - \tan^{-1}\frac{z(a+x)}{cb_1(b-y)} - \tan^{-1}\frac{z(a+x)}{cc_1(b+y)} - \tan^{-1}\frac{z(a-x)}{cd_1(b+y)},$$

$$\int_{-a}^{+a}\int_{-b}^{+b}\frac{\partial^2 \log\left(\frac{z}{c}+R_1\right)}{\partial z^2}dx'dy'$$

$$= -\frac{1}{c^2}\left[\tan^{-1}\frac{c(a-x)(b-y)}{za_1} + \tan^{-1}\frac{c(a+x)(b-y)}{zb_1} + \tan^{-1}\frac{c(a+x)(b+y)}{zc_1} + \tan^{-1}\frac{c(a-x)(b+y)}{zd_1}\right] = \frac{\theta_{s1}}{c^2}, \qquad (33)^4$$

(*Equation 33 continued on next page*)

[4] The first, second and fourth of equations (33) are similar to expressions given for the elastic theory by A. E. H. Love, *Philosophical Transactions*, Royal Society of London, Vol. 228, Series A, 1929.

$$\int_{-a}^{+a}\int_{-b}^{+b}\frac{\partial^2 \log\left(\frac{z}{c}+R_1\right)}{\partial x \partial y}\,dx'dy' = \log\frac{\left(\frac{z}{c}+a_1\right)\left(\frac{z}{c}+c_1\right)}{\left(\frac{z}{c}+b_1\right)\left(\frac{z}{c}+d_1\right)},$$

$$\int_{-a}^{+a}\int_{-b}^{+b}\frac{\partial^2 \log\left(\frac{z}{c}+R_1\right)}{\partial x \partial z}\,dx'dy' = \frac{1}{c}\log\frac{(y-b+a_1)(y+b+c_1)}{(y-b+b_1)(y+b+d_1)},$$

$$\int_{-a}^{+a}\int_{-b}^{+b}\frac{\partial^2 \log\left(\frac{z}{c}+R_1\right)}{\partial y \partial z}\,dx'dy' = \frac{1}{c}\log\frac{(x-a+a_1)(x+a+c_1)}{(x-a+b_1)(x+a+d_1)}.$$

Corresponding values for functions of $(cz + R_2)$ are obtained from equations (33) by substituting $1/c$ for c throughout. The distances a_1, b_1, c_1, d_1 and a_2, b_2, c_2, d_2 are explained on Fig. 4.

The value for $\int\int \frac{\partial^2 \log\left(\frac{z}{c}+R_1\right)}{\partial z^2}$ which equals θ_{s1}/c^2 is of special interest. In this expression θ_{s1} is the solid angle subtended at the point $(x, y, z/c)$ by the loaded area. The solid angle is defined as the area on a sphere of unit radius intersected by the elements extending from the point $(x, y, z/c)$ to the bearing area.

The expression for σ_z then becomes

$$\sigma_z = -\frac{w}{2\pi(c^2-1)}(c^2\theta_{s1} - \theta_{s2}). \tag{34}$$

The analogy to the two dimensional formula for uniform load (Fig. 2) is striking.

It can be shown that equation (34) is true for a bearing area of any shape subject to a uniform load. It is not confined to rectangular bearing areas.

EVALUATION OF CONSTANT, c.

The constant, c, should be evaluated by comparison with test data. As a short cut it can be found in terms of the concentration factor, n, developed by Dr. Ing. O. R. Froelich [5] and John H. Griffith, M. Am.

[5] "Drukverdeeling in Bouwgrond," *De Ingenieur*, April 15, 1932, p. B-52.

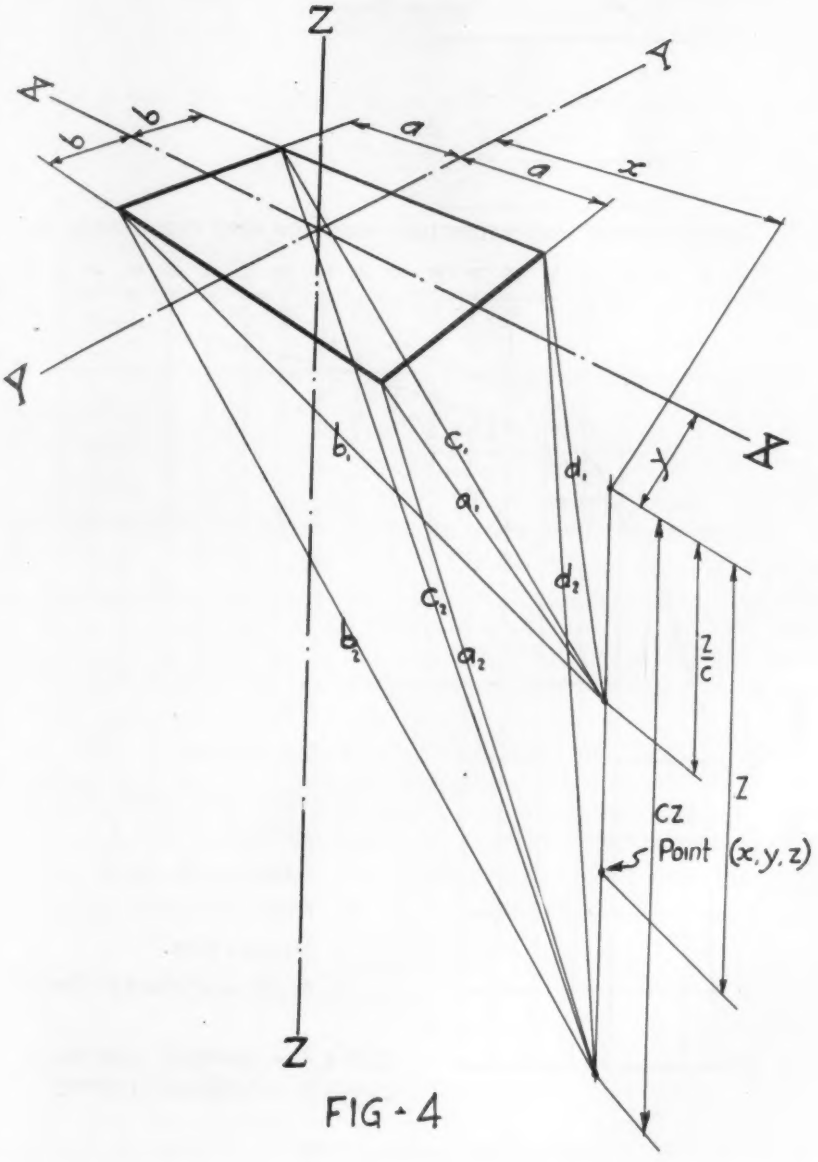


FIG - 4

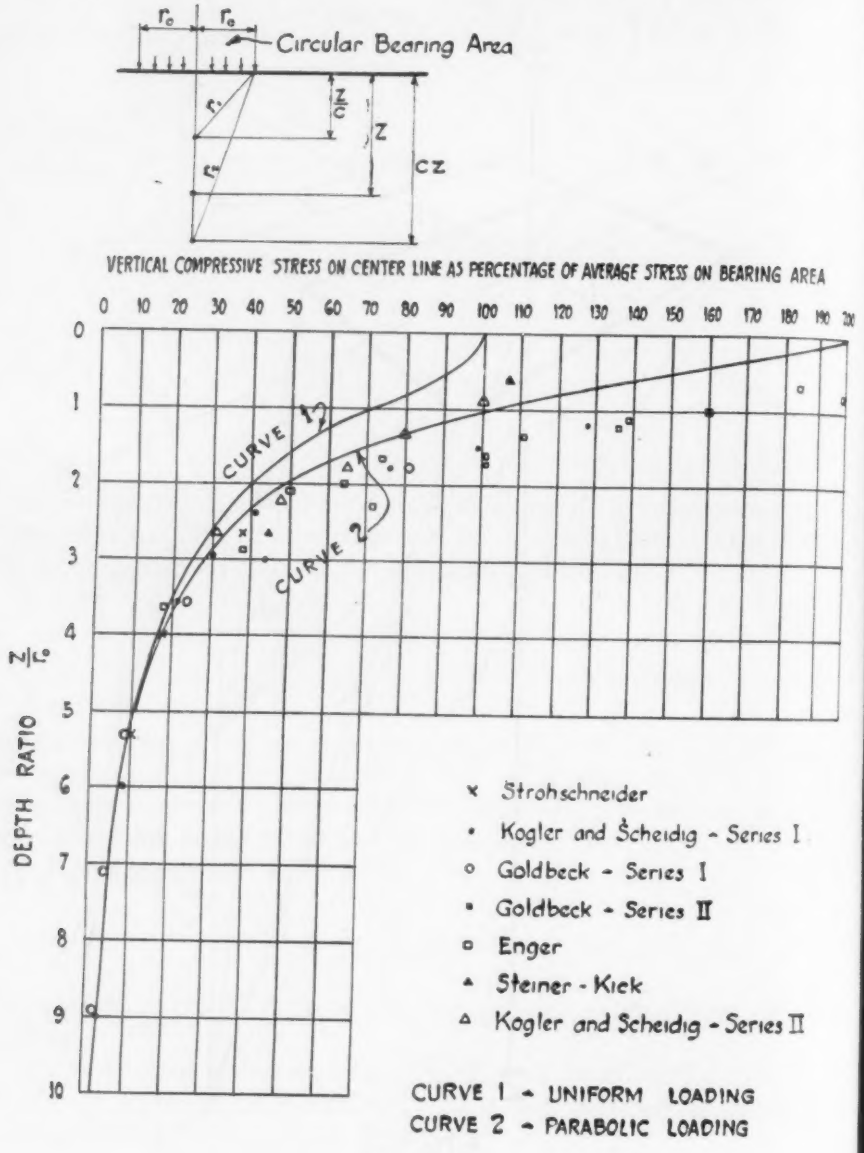

r₀ r₀
Circular Bearing Area
z/c
Z
cz
VERTICAL COMPRESSIVE STRESS ON CENTER LINE AS PERCENTAGE OF AVERAGE STRESS ON BEARING AREA
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
DEPTH RATIO z/r₀
0 1 2 3 4 5 6 7 8 9 10
CURVE 1
CURVE 2
Strohschneider
Kogler and Scheidig - Series I
Goldbeck - Series I
Goldbeck - Series II
Enger
Steiner - Kiek
Kogler and Scheidig - Series II
CURVE 1 - UNIFORM LOADING
CURVE 2 - PARABOLIC LOADING

FIG. 5

Soc. C. E.[6] According to Froelich and Griffith the direct stress directly under a concentrated load is given by the formula

$$\sigma_2 = -\frac{Pn}{2\pi z^2}. \tag{35}$$

When $x = y = 0$, $R_1 = z/c$ and $R_2 = cz$. Then from equation (30)

$$\sigma_z = -\frac{P(c^4 + c^2 + 1)}{2\pi z^2 c^2}. \tag{36}$$

By equating equations (35) and (36)

$$c^2 = \tfrac{1}{2}(n - 1 \pm \sqrt{n^2 - 2n - 3}). \tag{37}$$

These values are seen to be reciprocals, so again the plus sign will be used for c and the minus for $1/c$.

Mr. A. E. Cummings,[7] M. Am. Soc. C. E., has summarized the results of seven different series of experiments made at different places and at different times over a period of more than 50 years. All used circular bearing plates resting on different kinds of sands, and all measured the vertical compressive stresses. It is remarkable how closely they agree. In Fig. 5 the compressive stress under the center of the bearing area is plotted for different depths.

Cummings showed that a concentration factor of 6 produced a curve agreeing closely with the measured stresses. Using this in equation (36), it is found that $c^2 = 4.79$.

This value of c^2 is for the three dimensional analysis. c^2 for two dimensions, as given by equation (11), has a slightly different value. On Fig. 6 values of c^2 for two and three dimensional analyses and values of k_1 and k_2 are plotted for various values of E/G. These are based on an assumed value of u of .33. For a soil having a concentration factor of 6 values of these constants are

$$\begin{aligned} c^2 \text{ (2 dimensional)} &= 4.46, \\ c^2 \text{ (3 dimensional)} &= 4.79, \\ k_1 &= 2.13, \\ k_2 &= .282, \\ E/G &= 5.35. \end{aligned}$$

These values are only tentative ones and are for sand. For other soils they may be substantially different.

[6] "Pressures under Substructures," *Engineering and Contracting*, March, 1929, pp. 113–119.

[7] "Distribution of Stresses Under a Foundation," *Transactions Am. Soc. C. E.*, Vol. 101, 1936, p. 1072.

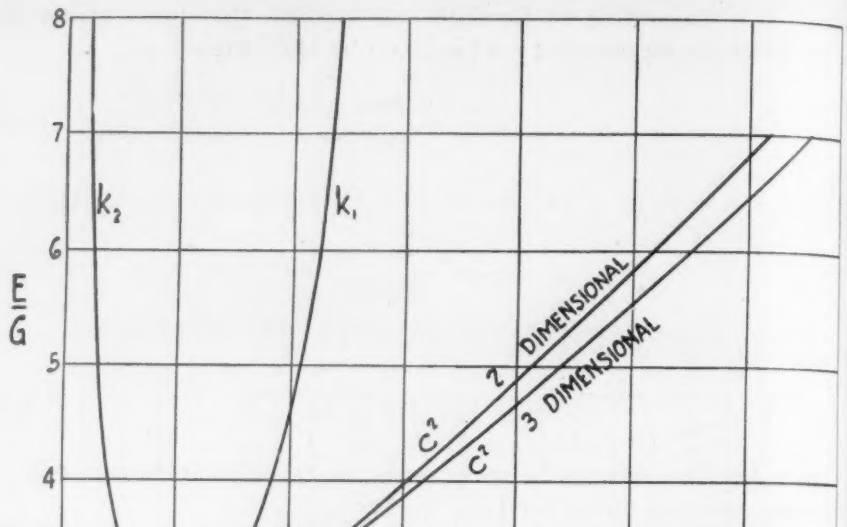


FIG. 6

COMPARISON WITH MEASURED STRESSES.

For a circular bearing area σ_z directly under the center can be readily found by means of equation (34)

$$\sigma_z = -w\left[1 - \frac{cz}{c^2 - 1}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)\right]. \tag{38}$$

On Fig. 5, Curve 1 is a plotting of this equation. The meaning of r_1 and r_2 is explained on this figure.

The agreement with measured stresses is quite satisfactory at points at some distance from the surface. Near the surface the theory gives values too small. However, as Cummings [7] and Prentis and White [8] explain, the loading on the under side of the bearing plate is not uniform but greater near the center, and less near the edges. On the assumption that the intensity of loading follows a parabolic distribution with a value of $2w$ at the center and zero at the edge of the plate, the

[8] "Underpinning, Its Practice and Applications," by Edmund Astley Prentis and Lazarus White, Columbia University Press, New York, 1931, p. 240.

compressive stress under the center of the plate is

$$\sigma_z = -2w\left[1 - \frac{2z^2}{r_0^2} - \frac{2cz}{(c^2-1)r_0^2}(r_1 - r_2)\right]. \qquad (39)$$

This is shown as curve 2 on Fig. 5, and is seen to agree closely with the measured stresses. Near the surface curve 2 is in good agreement with the experiments of Kogler and Scheidig (Series II) and those of Steiner-Kick, but departs from the experiments of Enger. However, it should be realized that Enger did not use a soil extending indefinitely downward, as the theory assumes, but a comparatively thin bed of sand resting on an unyielding steel plate. All things considered, the agreement with measured stresses is satisfactory.

HORIZONTAL PRESSURES AGAINST A VERTICAL RETAINING WALL.

The theory here given deals with a soil of infinite extent in both horizontal directions, and under an external load every point undergoes a deflection to a new position. It is assumed that a retaining wall is immovable and therefore prevents the deflection of elements adjacent to it in a direction normal to its surface.

In Fig. 7 let the face of the retaining wall coincide with YZ plane. The wall then prevents any deflection in the X direction at this plane, caused by the system of loads, P, acting upon the soil. Assume for the moment that instead of being interrupted by the wall the soil continues indefinitely to the left of the YZ plane. Then the theory here presented would apply and due to the loads, P, points originally on the line OZ would deflect horizontally to the position shown by the dotted line $O'A'$. Now assume a system of imaginary loads, P', exactly symmetrical about the YZ plane to the loads P. The action of these, which can be called the "reflected loads," would cause points on the line $O'A'$ to return again to the line OZ. They would then occupy the positions they would have were the retaining wall in place. It can therefore be concluded that the horizontal stress at any point is the sum of the stresses due to the loads P and due to the "reflected loads" P'. At the surface of the wall the horizontal stresses are then double the values given by the theory here presented due to the applied loads.

CONCLUSION.

There are few fields in structural engineering where the discrepancies between mathematical theory and actual conditions are as great as in the determination of stresses under foundations. Stresses given by the classical theory considering the soil an elastic solid and those known to exist in soils are far apart. This paper presents a mathematical analysis which is in close agreement with stress measurements. It is

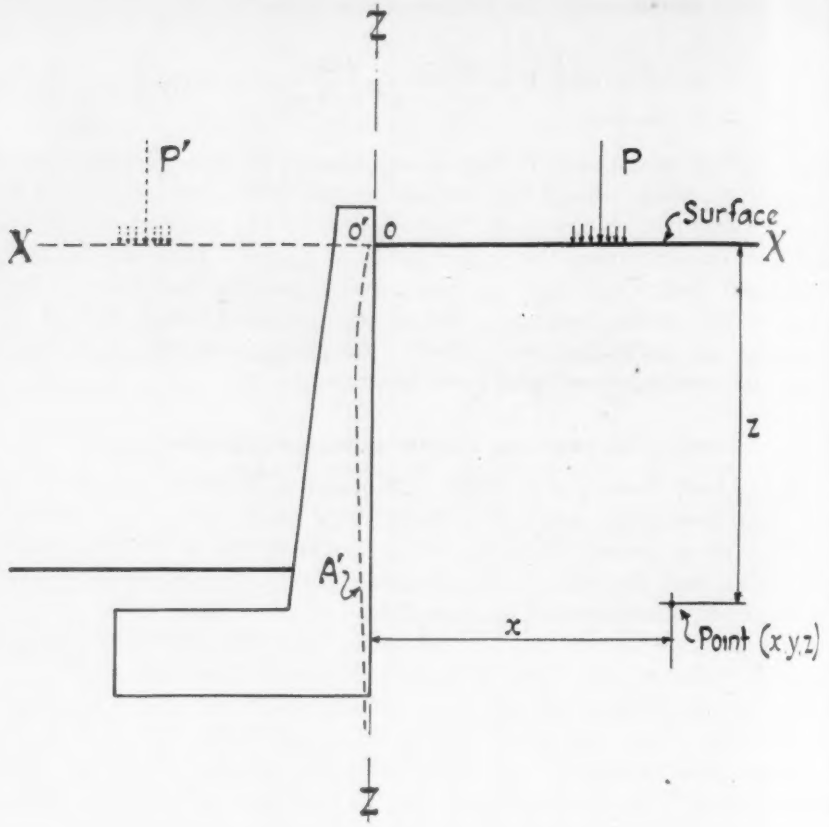


FIG. 7

more general than the classical solution since it considers the soil a substance in which the ratio of E to G is not fixed but can be determined for a particular soil. It is, in short, an effort to close the wide gap existing between mathematics and engineering in foundation work.

APPENDIX I.

Notation.

E Modulus of elasticity in compression.
G Modulus of elasticity in shear.
K_1, K_2 Constants.
P Concentrated load.
R_1 Distance from a point $\left(x, y, \frac{z}{c}\right)$ to point of application of load.
R_2 Distance from a point (x, y, cz) to point of application of load.
a, b Dimensions of rectangular bearing area.

a_1, b_1, c_1, d_1 Distances from point $\left(x, y, \frac{z}{c}\right)$ to corners of rectangular bearing area.

a_2, b_2, c_2, d_2 Distances from point (x, y, cz) to corners of rectangular bearing area.

c Soil constant.

k_1, k_2 Soil constants.

n Concentration factor.

r_0 Radius of circular bearing area.

r_1 Distance from point $\left(0,0, \frac{z}{c}\right)$ to edge of circular bearing area.

r_2 Distance from point $(0,0,cz)$ to edge of circular bearing area.

w Intensity of surface loading.

x, y, z Coordinates of any point.

x', y' Coordinates of a point on surface.

$\gamma_{xy}, \gamma_{xz}, \gamma_{yz}$ Shearing strains.

$\epsilon_x, \epsilon_y, \epsilon_z$ Elongations.

$\theta, \theta_1, \theta_2$ Angles.

$\theta_s, \theta_{s1}, \theta_{s2}$ Solid angles.

μ Poisson's ratio.

$\sigma_x, \sigma_y, \sigma_z$ Intensity of compression.

T_{xy}, T_{xz}, T_{yz} Intensity of shear.

ϕ Stress function.

Quicker Food Analyses.—Amino acids are now sharing the nutrition limelight with vitamins. The amino acids are the "building blocks" in proteins, stuff of which body tissues are built. With protein foods assuming increasing importance in war and post-war plans for world food supply, nutrition chemists face the challenge of speeding up research on protein values of everyday foods.

A step toward speedier analysis of foods has been achieved in protein research laboratories of the U. S. Department of Agriculture where short-cut methods have been developed to determine two of the important amino acids directly in foods. Drs. D. Breese Jones and M. J. Horn have worked out a method for determining tryptophane. This new way reduces from weeks to days the time formerly required to make such analyses. Dr. F. A. Csonka, H. Lichtenstein and Dr. Charles A. Denton have developed a new method for cystine. Using color-measuring instruments, the chemists ascertain the quantities of these amino acids in foods by the intensity of color produced when the food is combined with certain chemicals. Cystine gives a red hue; tryptophane, blue. Like other amino acids, cystine and tryptophane are found abundantly in animal protein foods. Of the plant foods, soybeans and peanuts are good sources of cystine, and navy beans are relatively high in tryptophane.

Although there are hundreds of kinds of proteins in foods, all of these are made up of combinations of the approximately 22 amino acids, 8 of which—including tryptophane—are essential to the growth and well-being of the human body. Eggs, milk, meat and other foods of animal origin have long been recognized as good sources of high-quality protein, that is, protein that contains the essential amino acids. More exact knowledge of proteins will show to what extent plant sources, such as beans and cereals, can be used to supplement the animal protein foods which are—from a world standpoint—short in supply.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

CALIBRATION OF ARC LAMPS FOR TESTING COLORFASTNESS TO LIGHT.

Work has been in progress at the Bureau for several years on a reference standard lamp for testing colorfastness to light of textiles, paper, and similar materials, and on means for calibrating, in terms of this standard, the lamps used in laboratories throughout the country. The purpose is to provide a reliable method for expressing colorfastness to light in "standard fading hours."

Recently a survey was made of the relative fading abilities of some 46 lamps in 21 different laboratories, in order to arrive at an average value and to demonstrate the need for calibration. The standard lamp and proposed method of calibration are described briefly in the Bureau's Letter Circular LC785, and the results of the survey are given.

The survey was made by distributing test strips of paper dyed blue which were exposed for exactly 20 hours in each unit, and were then measured to determine the change in reflectance. The variation of from 0.405 to 0.092 found, reveals the great need for a standard means of calibrating the lamps.

In the proposed method of calibration, paper dyed blue made in the Bureau's paper mill is used. A strip of the paper is exposed in the lamp for a suitable period of time, say for 20 hours. The strip is then compared visually with a strip of the same calibration paper which has been exposed in the reference standard lamp in steps of 16, 18, 20, and 22 standard fading hours. The time of exposure in the lamp being calibrated that is equivalent to one of the steps of exposure in the reference standard lamp can be determined in this simple manner within 10 per cent. or possibly better. Thus, the lamp can be calibrated in terms of the reference standard lamp and therefore in terms of any other similarly calibrated lamp. The calibration can be repeated as often as the particular installation requires. Laboratories desiring to try the paper will be supplied with unexposed test strips and with a book of strips which have been exposed in the reference standard lamp for 16, 18, 20 and 22 hours. They will be asked to comment on their experience with the paper to guide any further work that seems necessary. Requests for the paper, and for LC785, which are furnished without charge, should be addressed to the National Bureau of Standards, VII–2, Washington 25, D. C.

* Communicated by the Director.

EVALUATION OF ANALYTICAL FILTER PAPERS.

As part of a Bureau investigation of analytical filter papers, having as its ultimate goal the development of standards of quality, a suitable testing procedure has been developed. The various tests included in this procedure are described and discussed by B. W. Scribner and W. K. Wilson in the May *Journal of Research* (RP1653).

The testing methods, which are related to the peculiar requirements of analytical filter papers, comprise tests for rate of flow of water, retention of fine precipitates, and content of ash. Measurement of the rate of flow of water through the papers was such an extensive project in itself that a separate report on this portion of the work was made by F. T. Carson and H. Bogaty in *J. Research* NBS, **33**, 353; RP1613 (November 1944). A method for bursting strength of wet paper was also developed.

Other tests considered to be desirable for a thorough evaluation of the papers are thickness, weight per unit area, alpha cellulose, copper number, and acidity (pH). Standard methods are available for these determinations. From the thickness and weight, the density can be calculated. The other tests are of importance because of their relation to the purity of the cellulose and the stability of the papers. As has been found at the Bureau for papers in general, filter papers that had become brittle on aging were characterized by low alpha cellulose and high copper number, evidences of degraded cellulose. These were acid-washed papers and it is probable that the acid treatment was either too severe or that the acid, which is very destructive to paper, had not been entirely washed out. In some instances, brittle paper had a high acidity. Another consideration with respect to degraded cellulose is that it is soluble in some solutions.

The tests are being applied to the various types and grades of papers of both foreign and domestic origin that are available at present, so as to obtain comprehensive data for standards of quality.

MOLECULAR WEIGHT OF CELLULOSE ACETATE.

The intrinsic viscosities and osmotically-estimated number-average molecular weights of a series of cellulose acetate fractions have been measured by Arnold M. Sookne, Research Associate, and Milton Harris, Director of Research, both of the Textile Foundation. As shown in RP1654 in the May *Journal of Research*, it was found that within the range of chain lengths investigated (number-average molecular weight, $\bar{M}_n$, up to 130,000) the number-average molecular weights are proportional to the intrinsic viscosities in acetone solutions, in agreement with Staudinger's rule and the results of Kraemer. An estimate is provided of the relative homogeneity with respect to molecular size of the fractions and the starting material from which they were prepared.

POLYMOLECULARITY AND MECHANICAL PROPERTIES OF CELLULOSE ACETATE.

The tensile strengths, ultimate elongations, and folding endurances of films prepared from a series of cellulose acetate fractions and blends were studied by Arnold M. Sookne and Milton Harris. When the mechanical properties are plotted against the intrinsic viscosities (or relative weight-average degrees of polymerization) the results for the fractions and different blends fall on separate curves. In contrast, when the mechanical properties are plotted against the number-average degrees of polymerization, the results for the fractions and all of the blends fall approximately on a single curve for each property. The results, which will be published in full as RP1655 in the *Journal of Research* for May, are shown to be qualitatively consistent with the hypothesis that the mechanical properties of blends are the weight-averages of the properties of their components: i.e.,

$$\text{Property blend} = \frac{\Sigma w_i P_i}{\Sigma w_i},$$

where w_i is the weight of the molecular species with a mechanical property P_i. The results emphasize the importance of the determinations of the number-average degree of polymerization in studying commercial polymolecular materials.

SEPARATION OF HYDROCARBONS BY ADSORPTION.

In RP1652 in the May *Journal of Research*, Beveridge J. Mair describes a new method for separating and determining aromatic and mono-olefin hydrocarbons in mixtures with paraffins and naphthenes by adsorption. The mixture to be analysed is introduced into the top of a column of silica gel. When the liquid level just reaches the top of the silica gel, a suitable desorbing liquid, such as ethyl alcohol, is added. The desorbing liquid forces the hydrocarbon portion down the column, during which passage the hydrocarbon portion is fractionated according to the adsorbability of the various components. These components issue from the bottom of the column in the following order: Paraffin plus naphthene, mono-olefin, and aromatic hydrocarbons. The analysis is made by determining the fraction of the total volume constituted by each of these classes.

Results of the analyses of five solutions containing aromatic and paraffin hydrocarbons, and three solutions containing aromatic, mono-olefin, and paraffin hydrocarbons are given. A procedure is outlined for determining the aromatic content of a straight-run petroleum distillate, as in the gasoline or kerosine fractions.

HEAT LOSSES FROM SLAB FLOORS.

Results of a study of heat losses from slab floors have been released as Building Materials and Structures Report BMS 103, "Measurements of Heat Losses from Slab Floors," by R. S. Dill, W. C. Robinson and H. E. Robinson. Slab floors are widely used in low-cost housing, and exact information concerning their heat transfer characteristics is desirable.

In a structure specially designed for the purpose, four concrete floors were laid directly on the ground, and three concrete floors and one wood floor over crawl spaces, representing common types of construction. The floors, insulated from each other, were enclosed in separate compartments, the walls and ceilings of which were heavily insulated. Heat-transfer properties of these floors under varying conditions, as well as ground temperatures at different depths, down to 13 feet below the surface, are reported in the paper. In addition, factors based on these observations are suggested for estimating floor heat losses.

A summary of the measurements shows that the heat loss through the center of the floors laid on the ground is relatively small when the enclosing structure is continuously heated, that the heat loss is decreased by insulating the outside edges, and that, as regards warmth in winter, insulation at the exposed edges is more important than insulation under the center of floors of this type.

Of the floors laid over crawl spaces, the edge loss is found to be small for the wood floor, and, although this loss is considerable for a concrete floor insulated under the center, construction difficulties may make it impracticable to insulate the edges. It is further concluded that, as far as warmth or heat loss is concerned, a concrete floor may as well be laid on the ground as over an unheated crawl space.

Copies of BMS103 are available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C. at 10 cents each.

LIGHT-WEIGHT AGGREGATE CONCRETE.

The desirable properties of light-weight aggregate concrete—low cost, light weight, heat insulation value, and low shrinkage upon drying—are in part sacrificed if the concrete contains more cement than that needed to meet an essential requirement, such as strength. Despite this, the concrete for buildings often contains about 6 sacks of cement per cubic yard, which usually is more than is needed to attain the properties desired for the hardened concrete, and more than the amount commonly used for similar construction in Europe. The extra amount is added chiefly to improve the placeability of the concrete, thereby lowering the cost of placing and compacting, because leaner concretes are harsh and are not readily compacted.

Other methods of increasing the workability of lean concretes containing a light-weight burned-clay aggregate were investigated at the Bureau. Changes in the grading of the aggregate accomplished something, but a marked improvement was brought about by adding to the mixture a small amount of an organic compound that caused foaming during the mixing of the concrete and the entrainment of air. Concrete having only 3 sacks of cement per cubic yard had excellent workability when the entrained air was about 20 per cent. of the volume of the concrete. Such a concrete had a compressive strength of 500 lb./in.^{2}, which is sufficient for many uses, and possessed the other desirable properties associated with light-weight concrete.

MODULAR PLANNING OF NEW BUILDING CONSTRUCTION.

The Bureau has participated actively for some time in a project for coördinating dimensions of building materials and equipment and for correlating building plans and details with such dimensions. This promises to develop into a major factor in lowering the cost of construction and improving the quality of structures. Sponsored jointly by the American Institute of Architects and the Producers' Council, Inc., and carried on under the procedure of the American Standards Association, the project has the support of many manufacturers of building materials who plan to turn out their products in accordance with standardized dimensions that will make it possible for materials to be assembled in the finished structure with a minimum of cutting and fitting.

"Modular planning" is based on a 4-inch unit or "module" that serves as the spacing for a uniform three-dimensional grid to which the building layout and details are referenced. Its use is expected to lower construction costs by saving time for architects and engineers, by permitting a reduction in the number of sizes of parts that must be produced and kept in stock by manufacturers, by accelerating construction, and by reducing the possibility of error. Its principles are being applied to advantage by the City of New York in planning important postwar work.

The Coming Age of Plastics.—The last quarter century has witnessed most of the growth of the plastics industry, and the speed of development has been quicker and quicker as the years have passed, points out John C. Cowan of the U. S. Department of Agriculture in an article on the subject. Cowan is one of the research workers at the Northern Regional Research Laboratory, where several notable contributions to the development of plastics have been made.

Although the plastics industry traces back 75 years to 1870, when Hiatt discovered that camphor and cellulose nitrate made a plastic closely resembling ivory, the development was gradual for the first fifty years, and by 1920 Cowan notes, "plastic articles were of relatively little importance in industry or the home."

In 1930, he notes, the industry produced about 37,500,000 pounds of plastics valued at about $75,000,000, or $2 a pound. In 1940, the industry had been multiplied by eight, with an output of 300,000,000 pounds averaging about $2 a pound in value. Estimated production in 1944 indicates a doubling since 1940 with an output of about 700,000,000 pounds valued at $1,800,000,000, or about $2.50 a pound.

Since Pearl Harbor, plastics have replaced natural rubber for many uses, says Cowan. He points out that plastics have contributed enormously in the development of superior aircraft which are a decisive factor in the war.

Of the future, he says it is difficult to predict, but he comments that "it is certain that the plastics industry will continue to have an enormous growth for some time to come. One plastic which has not been developed fully is polystyrene. If natural rubber or new synthetic rubbers replace Buna S for many uses after the war, styrene will be available in quantity. Also by combining sheet metals, adhesives and foam plastic, unusually strong and light weight construction materials may be produced. It looks as if we have only seen the beginning of the plastics industry."

R. H. O.

THE FRANKLIN INSTITUTE.

MEDAL DAY PROCEEDINGS.

The annual reception, dinner and presentation of awards, known as Medal Day, took place at The Franklin Institute beginning at 5:30 on the evening of Wednesday, April 18, 1945, in Franklin Hall. Mr. Charles S. Redding, President of the Institute, presided.

Reception.

The reception preceding the dinner was given by the Hostess Committee of The Franklin Institute. Four hundred and thirty persons were present. The reception was held in a room adjoining the Chemistry Section which allowed ample space for the guests. Dinner was served in Franklin Hall at 6:15 P.M.

Calling the meeting to order, Mr. Redding asked the audience to stand in silent tribute in honor of our late President, Mr. Roosevelt.

The program was continued as follows:

Mr. Redding: We are again honored by having with us this evening Lieutenant Guy Marriner, a member of the Institute staff now on leave in the Armed Forces. Many of us will remember Guy Marriner's Sunday afternoon piano recitals and are looking forward to their resumption when Lieutenant Marriner returns to civilian life. I will ask Lieutenant Marriner to rise for a moment and then open our meeting with the playing of our National Anthem.

The assembly stood at attention.

After expressing the pleasure of the audience the President called upon Richard T. Nalle, Vice President of The Franklin Institute, Chairman of the National Franklin Committee, to propose a toast to our patron, Benjamin Franklin. Mr. Nalle complied and the toast was drunk (in water).

Stated Monthly Meeting.

The President called upon the Sponsors for the 1945 Medalists to take the places reserved for them in chairs immediately below the head table, facing the audience.

He then announced that this was a regular monthly meeting of The Franklin Institute and that the minutes of the February meeting, having been published in the March Journal, were to be voted upon. As there was no dissent the minutes were declared approved as printed.

Mr. Redding then greeted the audience as follows:

MR. REDDING: And now, on behalf of the Officers and Board of Managers of The Franklin Institute, I am very happy to welcome all of you. Medal Day is always a significant occasion in the Institute's year. It is on this annual occasion that the Institute presents its awards to men and women who have made outstanding contributions in the fields of Science and the Mechanic Arts. It is always a happy occasion. It brings together a fine group of people to do honor to those who have been selected to receive the awards. Again, I welcome you all, most heartily.

Those of you who attended last year's Medal Day exercises will note that we do not have a record-breaking attendance this year, as we did on the previous occasion. This year, because of the ruling of the Office of Defense Transportation, we did not send invitations to members and friends living beyond a twenty-five mile radius of Philadelphia. However, announcements of the occasion were sent to all members and former medalists living beyond the twenty-five mile zone with an explanation as to why an invitation was not sent. Despite the O.D.T. regulations, reservations were received from 406 members and friends, not including our Medalists and their wives.

I am happy to report that since last Medal Day 1168 persons have been elected to membership in The Franklin Institute. Of that number 33 are attending this dinner. Will those new members please stand for a moment in order that we might greet them? Thank you—we are delighted to have you with us and hope that you will make full use of the Institute's facilities.

FORMER MEDALISTS.

It is our custom to invite to our Medal Day meetings as our guests those who, in previous years, have received Franklin Institute Medals. There are 17 such with us this evening. This is a smaller number than usual, as due to the O.D.T. regulations to which I previously referred we were unable to invite those living outside the Philadelphia commuting area. To you former medalists I extend a particularly warm welcome. You are in a very real sense part of The Franklin Institute family and we are always glad to have you with us. I will read the names of the former medalists who are with us in the chronological order in which they received their medals and will ask each Medalist to rise as his name is called and to remain standing until the complete list is read. Will the audience please withhold applause until the last name is announced.

FORMER MEDALISTS ATTENDING MEDAL DAY—1945

Year of Award	Medalist	Medal
1904	Clamer, Dr. G. H.	Cresson
1920	Kothny, Mr. G. L.	Longstreth
1920	Leeds, Mr. Morris E.	Longstreth
1921	Adams, Dr. L. H.	Longstreth
1923	Parks, Mr. Harry S.	Longstreth
1924	McBride, Mr. Thomas C.	Longstreth
1930	Chrisman, Mr. Charles S.	Wetherill
1932	Dashiell, Mr. Philip T.	Clark
1935	Shrader, Dr. James E.	Wetherill
1936	Hall, Mr. Peter P. G.	Longstreth
1937	Haug, Mr. John S.	Longstreth
1938	Ward, Mr. Alger L.	Levy
1939	Chaney, Dr. N. K.	Potts
1939	Wilford, Mr. E. Burke	Certificate of Merit
1941	Wilson, Dr. Benjamin J.	Longstreth
1944	Ennis, Mr. Joseph B.	Henderson
1944	Stokes, Mr. J. Stogdell	Longstreth

MR. REDDING: Since assuming the Presidency of The Franklin Institute, it has been with very real pleasure that I have recognized during our Medal Day meeting the two living past Presidents, Mr. Nathan Hayward and Mr. Philip C. Staples. Since last Medal Day, the Institute has suffered an irreparable loss in the death of Mr. Hayward. The Franklin Institute was always close to his heart and was one of his prime interests. We all miss his kindly and gracious counsel and advice. His name will always be associated with this fine building, as it was under his Presidency that it was built.

Mr. Hayward was succeeded by Mr. Staples who served faithfully and well during a most trying period in which the Institute felt the full effect of the great depression. To him we owe much for what was accomplished under his administration. After retiring from the Presidency he has continued as an active member of the Board of Managers, ever ready to do what he can for the welfare of our beloved institution. Unfortunately, Mr. Staples is unable to be with us this evening.

REPORT OF THE SECRETARY.

MR. REDDING: It is part of the business of our Stated Meetings to have a report from Dr. Henry Butler Allen, Secretary of the Institute and Director of our Museum. It is particularly fitting that he should make a report at our Medal Day meetings when we have present many who would not otherwise hear at firsthand about what is going on at the Institute in these war years. May I say again that which I said last year, that Dr. Allen is a very busy man, combining his normal duties with the responsibilities attending the war work being done at the Institute and the responsibilities which he carries as Deputy Chief of

Division 1, National Defense Research Committee. I know you will be glad to hear his report, for which he has chosen a title, namely, "Another Year."

DR. ALLEN: Mr. President, Honored Guests, Fellow Members and Friends:

Another year has borne us along the tide of history. It has brought our country, and so all of us, to the threshold of victory. Each success of our Armed Forces means that we at home must redouble our efforts to hasten peace.

For the last few years now I have been telling you that your Franklin Institute has contributed valiantly to the war effort. While we must still remain silent on the direction of those efforts, I am proud to point out that they are of sufficient importance to have gained for us during the past year the Ordnance Distinguished Service Award of the United States Army—an honor not lightly bestowed.

Another indication of progress is that whereas we had 100 war workers last year at this time, we now have 135 on our rolls. Our total number of employees in this building is 294. (No small achievement in these days of scarcity of scientific personnel.) And as I said last year, we plan to continue an enlarged applied science research after the war, primarily as industrial research for companies in this area. But at the same time we recognize the need, and we plan to continue a certain amount of our research for our Army and Navy in their peacetime preparedness program; until the day comes when that form of insurance is clearly no longer necessary.

It has been our good fortune that without sacrifice to our war service we have been able to contribute to the uplift of public morale through our museum and planetarium, our library and lectures;—and especially to that portion of our population which is all important—I mean the children.

You will be interested, and perhaps surprised, to know that during the past year 60,868 young people have visited the Institute, an 89 per cent. increase over the previous year. This has been brought about by close coöperation with the Philadelphia Board of Public Education and parochial and private schools. Through our own Department of Museum Education, arrangements are made to bring classes of children to visit the museum—sometimes only a part of it, sometimes a quick tour, but usually under guidance, with the result that children invariably find a favorite section or exhibit, to which they return. In the planetarium it has been necessary to give special showings day after day in order to accommodate the large audiences.

Another innovation in education during the past year has been the establishing of two radio programs—with hearty collaboration from the broadcasting stations. If you should tune in WFIL any Monday at 2:15 you would be entertained, and instructed, by the visit of two young

people to Egbert, our mechanical man. At 1:45 on Tuesdays over WIP you will hear a more adult program, planned for the high schools. These programs are listened to in the classrooms throughout the city, to what good effect may be seen when I tell you our building was overrun with children during the recent Easter vacation. Our slogan for the schools is "Science is Fun" and the fact that children come here as individuals, outside of school hours, proves that in truth they find it so. In speaking of the children and their response to our activities, it is interesting to note that in January we mailed out, at the schools' request, over 4,000 pieces of reading matter, giving various phases of Franklin's life.

All this work is a great public service to the City and State. At a time when many are alarmed by unwholesome activities of our young people, you can take pride in the fact that your contributions to The Franklin Institute make it possible for us to provide an antidote, and that the eager response of the young people is a very hopeful sign. And it is an encouraging sign for another reason. This terrific war is taking its toll of young applied scientists in the armed services. A larger proportion of our children must be made interested in science.

Mr. President, these highlights of the past year are sufficient, I think, to let our members know that "Another Year" has not found the Institute wanting. I shall not take time to enumerate the progress made in our routine activities. I suggest, however, that those who have not already done so, should read the President's Report for 1944, published in the February JOURNAL of the Institute. It will prove interesting reading, and because it shows what *has* been done, it brings to mind a favorite adage of our patron saint.

"Words may show a man's wit, but actions his meaning."

I thank you.

A GLANCE AT THE INSTITUTE'S HISTORY.

MR. REDDING: Before proceeding to the main purpose of this meeting, the awarding of the Institute's medals, it is appropriate to again speak briefly concerning the method of selection of our medalists. Many in the audience are probably quite familiar with that procedure but our 1945 Medalists, in particular, might like to learn something about it.

Leading up to our present practice, may I ask you to go back with me about one hundred and twenty years—back to June, 1825. The Franklin Institute had then been in existence about one year and a half. Already it had published its first annual report, a document of 105 pages, including a list of its members numbering something over 600. Each member's occupation is listed and it is exceedingly interesting to see the wide range of occupations represented in the list. We find

fire-engine makers, saddlers, plasterers, blacksmiths, gold leaf manufacturers, the President of United States Bank (Nicholas Biddle) carpenters, attorneys-at-law, the Post Master, machinists, among which was Matthias W. Baldwin, a powder manufacturer (E. I. duPont), a Naval officer (Capt. James Barron), two Judges of the Supreme Court, a looking glass silverer, a saddle tree maker, mathematical and surgical instrument makers, and many others, including a corset maker.

Some may think today that in spreading membership in The Franklin Institute as broadly as we do, we are departing from the purposes for which the Institute was founded. A glance at the list of members I have just referred to should settle that question at once.

But, to get back to the year 1825, and specifically to June 2 of that year: On that date the Board of Managers of the Institute passed a resolution creating a committee of five to be known as the Board of Examiners. That was the forerunner of our present Committee on Science and the Arts, which committee now recommends to the Board of Managers those it thinks worthy to receive Franklin Institute awards.

At a meeting of the Board of Managers held July 14, in the same year, 1825, the name of that committee was changed to the Committee on Inventions, which name was retained until 1834.

The purpose of that committee was to report upon inventions submitted to it. Apparently the idea was to either encourage the inventor to go further with his invention or to discourage him for reasons given in the reports. The reports of the committee were sometimes printed in the Institute's JOURNAL and sometimes not. Perhaps the purpose of this committee can be expressed best by the following extract from the Annual Report of the Board of Managers of the Institute presented at the Annual Meeting held on January 17, 1833:

"The labours of the committee on inventions, ranking high in importance, claim the first attention, as from their nature they are least understood, without the circle of those who have occasion to feel their benefits. This committee have made but three reports through the Journal of the Institute during the past year, and the inference is natural that as, in this age of invention, they must have had more opportunities than these of expressing their opinion, that they have been inactive. But this inference is founded in a misapprehension of their duties. The committee are to serve as counsellors to inventors, not always as reporters. An invention is submitted, and in a personal interview, or by letter, explained by the inventor; it is freely discussed; its novelty and its merits examined. In perhaps a majority of cases, the inventor is satisfied, from the views given him, not to present the invention to the public; in others, the inventor requests a written report, which he receives, and is often unwilling that it should come before the public, from whom he withdraws the invention. In the small number of cases then, in which an inventor desires the publication of a report, or in which he has brought his invention so far before the public that he cannot retract it, do the reports of this committee appear in print, as records of the time which they devote to their duties."

Unfortunately we do not seem to have any records of the activities of this Committee on Inventions other than those reports which it did print in the JOURNAL.

Apparently the Board of Managers of the Institute felt that something was lacking in the operation of the committee, for on January 9, 1834, by resolution of the Board; the name of the committee was changed to its present name, the Committee on Science and the Arts. Alexander Dallas Bache was made its chairman. He was Professor of Natural Philosophy at the University of Pennsylvania and preceded Dr. John F. Frazer in that chair. This is of interest to us today because Dr. John F. Frazer was the grandfather of Dr. John Frazer who is now, and for some years has been, Secretary of the Committee on Science and the Arts. It is also interesting to note that Dr. Bache was a direct descendant of Benjamin Franklin.

Dr. Bache almost at once placed the activities of the committee on a business-like basis. Regular minutes were kept and the complete record of the committee's work is in our archives, including practically all its reports, starting with No. 1. The case system which he set up has been carried through to this day. The latest case number is 3154. Dr. Bache served as Chairman of the committee for about 8 years, although not continuously. His influence is still felt by the committee.

In looking over the records, I was particularly interested in following through Case No. 3. Apparently this Case was first in the hands of the Committee on Inventions and was handed to the new committee to continue. The case is entitled "Spark Arrester"; it had to do with a device for preventing locomotives from sending out sparks. Apparently the Institute, or some individual or group through the Institute, had offered a prize for a successful spark arrester. This case is first mentioned in the minutes of the meeting of March 13, 1834. It was stated that several devices had been presented, but only three were considered worthy of trial, and that only two of those had been presented for trial. The committee stated that it had arranged to borrow a locomotive from one railroad, the Beaver Meadow Railroad, and the tracks of another, the Philadelphia and Trenton Railroad, for the purpose of trying out the two devices. Month after month went by awaiting the loan of the locomotive, but finally the test was made and reported upon in 1836, two years after the first mention in the minutes. Here we may note that delays in experimental work are not new.

The first of the devices reported was described in the report, as follows: It "consists of a series of revolving fan wheels placed horizontally one above the other near the top of the chimney or smoke pipe —the wheels or fans were placed nearly in contact one above the other having just sufficient space to admit of motion independently of each other and the twist of the fans reversed in the middle one so that its revolution should be in the opposite direction from the other two."

The rotation of these wheels or fans was to be induced by the steam passing up the stack. Tests proved that the sparks were fully arrested but that the fans or wheels cut down the stack opening to the point where it was not possible to secure enough draft to build up pressure in the boiler sufficient to enable the engine to move at more than a "moderate velocity." The committee, in reporting negatively upon this invention, stated: "This result could only be ascribed to one of the three following causes either the operation of the fans had been effectual in beating back and destroying the sparks or as the engineer who accompanied the committee supposed the obstruction of the draft being great the steam was necessarily so damp as to extinguish them . . . or what was considered highly probable the obstruction was so great as to prevent the creation of an upward current sufficiently powerful to raise the sparks to the top of the chimney. . . ."

The second was more ingenious. It consisted of a cone placed on top of the smoke stack with its axis horizontal, with a hole cut in the cone to receive the smoke stack, the cone swiveled on top of the stack and with a vane provided on the outside to keep the apex of the cone toward the wind. The open base of the cone was provided with a wire screen. This inventor foresaw the cutting down of the draft by the screen and used the cone device as an aspirator to produce additional draft to compensate. The committee also reported unfavorably upon this device. It found that the device did increase the draft but sparks did come through. It concluded that if the screen mesh were made fine enough to hold the sparks the device would be impractically large. It found also, as might be expected, that some means would have to be provided to clear the inner surface of the screen of accumulated ash. And then the final unfavorable point was that when the sparks and ash came out they were directed right to the Engineman, and that ended the case.

Prior art is a bugaboo of the inventor today. That is not new. Case No. 4 was the examination of a presumably new type of wind-mill. The alleged inventor did not get much encouragement, as can be seen from the last paragraph of the committee's report, the report being dated March 15, 1834:

"Case No. 4, Mr. Dugdale's Wind-mill

"Your committee deem it unnecessary to expatiate upon the merits of this Wind-mill; or to discuss the Patentee's claim to originality in his invention; but will merely refer all who are interested in the subject, to the Repertory of arts, and to the Edinburg Encyclopedia; in which they will find described, several mills operating upon the same principle; some of which closely resemble this one in the details of their construction.

"On behalf of the committee.

(s) J. C. Cresson"

What a wealth of interest there must be in the records of this committee. Just one more instance: On February 8, 1838, the committee made a report upon an electrical telegraph device submitted by one Samuel F. B. Morse. That report is in our archives. It was made five years before Congress passed the appropriation to put the telegraph to practical test.

In 1847 Morse had to defend his invention in the courts. Undoubtedly this letter, and here is the original, was in connection with that suit:

"Po'keepsie, March 15, 1848
Locust Grove.

"My dear Sir,

"You would confer upon me a great favor, if you could furnish me with the date of the *Exhibition of my Telegraph* before the Committee of the Institute, from the minutes of the Institute, regularly certified, by the President or Secretary. And if Mr. Trego could find the strip of paper written at that time and would send it to me, with his Signature upon it and attesting the fact, I should esteem it a great favor.

"I may need these documents in self defence. I do not mean the Report of the Committee this I have, it is dated Feby 8th, 1838, but at the close of the Report I perceive that the Stated meeting of the Comtee of Sciences and Arts of the Franklin Institute was held on that date who received the Report from a *Sub committee*. Consequently the Exhibition must have been some days previous. The precise date of the Exhibition I should like to verify.

"Believe me with sincere respect & esteem

Y. Mo. Ob. Servt.
(s) Sam. F. B. Morse."

"Hon. R. M. Patterson
Director of the Mint
Phila."

The first medal given by the Institute through its Committee on Science and the Arts, was the John Scott Medal. The Philadelphia Board of City Trusts, in 1835, placed the awarding of this Medal in the hands of the Institute. In 1919 the awarding of that Medal was taken from the Institute, for some reason which I do not now remember, and continued under the direct jurisdiction of the Board of City Trusts.

The first of the Franklin Institute Medals was the Elliott Cresson Medal instituted in 1848. The several other Institute awards have been set up since that time.

Perhaps I have bored you with this past history, but it was so interesting to me that I thought you might like to have it.

Now, to come back to today. The Committee on Science and the Arts long since gave up the examination of inventions to determine their practicability. Today and for many years it has devoted its efforts to selecting those persons whose outstanding work in science and the arts

entitles them to the recognition which a Franklin Institute award brings them. The awards are known and prized throughout the world.

The Committee on Science and the Arts comprises some 65 carefully selected members of the Institute who unselfishly give largely of their time to the work of the committee. It operates through sub-committees reporting to the main body. Each recommendation for an award made by a sub-committee is fully and frankly discussed in the main committee, and if the main committee acts favorably, the recommendation is submitted to the Board of Managers for its action. So, I can say to you gentlemen who tonight are to receive awards, they have not been made lightly—we know that you fully deserve them. In giving them we honor you; and in accepting them, you honor us.

Photo by Gladys Müller

RECIPIENTS OF AWARDS FOR 1945.

Seated (left to right): Lewis F. Moody, Harlow Shapley, Charles S. Redding, President of The Franklin Institute, Stanford C. Hooper, and Edwin A. Link. Standing: Rupen Eksergian, Gilmore D. Clarke, Sanford L. Cluett, Henry Butler Allen, Secretary and Director of the Institute, Greer Ellis, Walter J. Coppock, and Zay Jeffries.

AWARD OF MEDALS.

Mr. Redding called upon the first sponsor, Mr. C. H. Masland, 2nd.

MR. MASLAND: Mr. President, I have the honor of presenting a designer of a unique motor base which has valuable advantages when

used with belt driven machinery such as machine tools, air compressors, fans, etc.

The base adjusts the tension of the belt automatically by making use of the reaction torque of the motor. When a heavy load comes on the belt, the pull of the motor swings it on a pivot so that the belt is tightened. When the load is reduced, the torque becomes less and the motor swings the other direction by gravity, thus decreasing the belt tension and taking up the load with minimum slip.

It is, therefore, a great pleasure to present Walter J. Coppock for the award of a Certificate of Merit upon citation reading—

"In consideration of his design of a novel and theoretically sound motor base which gives automatic belt tension under widely varying load conditions."

MR. REDDING: Walter J. Coppock, by virtue of the power vested in me as President of The Franklin Institute, I have the honor to hand you herewith this Certificate of Merit together with a copy of the report which accompanies it.

I next recognize Mr. Lionel F. Levy.

MR. LEVY: We all marvel at the extraordinary performance of our battle planes and bombers, but do we ever stop to think of the fact that someone must have designed every one of the thousands of parts that make up these complex structures, and in so doing must have answered the question, "How strong must this part be?"

In many cases, the design of pieces of machinery may be based on the application of physical principles, but in probably a majority of cases, the stresses are not known and the form of the part is too complex for mathematical treatment, so that experiment and observation must be depended upon in the design.

It is in the solution of such complex problems that the use of brittle lacquer as developed by our Medalist has contributed so largely.

While not the original inventor of the use of lacquers for this purpose, our Medalist has perfected the whole technique of the method to a point where it is a most useful tool in the design of machine parts.

A thin film of a specially compounded lacquer is painted on the part where strains are to be studied and, after stressing the piece, the cracks that develop in the lacquer are examined and from their configurations the position and approximate size of the stresses can be determined.

His work has included the formulation of the lacquer, methods of application, and the calibration and interpretation of results.

Mr. President, I have the honor of presenting Mr. Greer Ellis, of Chicago, Illinois, to receive the Certificate of Merit—

"For his work in the development of brittle lacquers for strain measurements and in establishing a technique which makes possible a more dependable quantitative interpretation of the indications."

MR. REDDING: Greer Ellis, by the same authority I present you

herewith the Certificate of Merit and a copy of the report which accompanies it.

Mr. W. H. Fulweiler.

MR. FULWEILER: Most of us are old enough to remember the time when a beautifully fitting shirt would come back from the laundry with the sleeves an inch too short and the collar a size too small. Thanks to the work of our Medalist, this condition has been overcome by the extremely ingenious scheme of sufficiently compressing the cloth, while soft and pliable, and then ironing it in a way to maintain this compressed condition, whereby the shrinkage is eliminated. The commercial importance of our Medalist's work may be appreciated when we realize that over two billion yards were sanforized last year.

It is, therefore, a pleasure to present Mr. Sanford Lockwood Cluett for award of the Edward Longstreth Medal,

"In view of the fundamental nature and mechanical ingenuity displayed in the development of the process for the pre-shrinking of woven fabrics, known as Sanforizing."

MR. REDDING: Sanford Lockwood Cluett, by virtue of my office as President of The Franklin Institute, I present to you the Edward Longstreth Medal, Certificate, and copy of the report.

The chair recognizes Mr. Coleman Sellers, 3rd.

MR. SELLERS: Mr. President: I present a Medalist who has contributed to the health and pleasure of many people.

As a Consulting Engineer distinguished in both landscape and building architecture he has had a prominent part in combining them in what may well be called human welfare engineering, in planning large apartment house developments in cities, as well as many parks and playgrounds.

An especially notable example of such planning by our Medalist is Parkchester, a residential development in New York City.

Housing some 40,000 persons in 51 apartment buildings occupying only about one-fourth of the chosen site of 130 acres, the remaining land was developed for the welfare and enjoyment of the occupants of the apartment, in an extensive and beautiful acreage of shrub and tree planted parks, open air recreation areas, traffic safety roadways, parking spaces, and other facilities, a boon for city dwellers.

It is therefore a great pleasure to present Gilmore David Clarke for award of a Frank P. Brown Medal, upon citation reading:

"In consideration of his technical ability, foresight, initiative and outstanding leadership in the field of town and city planning."

MR. REDDING: Gilmore David Clarke, by power vested in me as President of The Franklin Institute, I present you the Frank P. Brown Medal, Certificate, and the copy of the report.

I recognize Dr. G. H. Clamer.

DR. CLAMER: Mr. President: I present a Scientist who has very

materially contributed to the advancement of metallurgical knowledge, particularly the knowledge of the structure of metals and their behavior under heat treatment and working.

In the practical application of such advancing knowledge to new problems he has conspicuously demonstrated that a keen observation, interpreted by a trained and prepared mind, leads to progress and development.

His career began as Assistant Professor of Metallurgy at the Case School of Applied Science. His merits as a research engineer were soon recognized and he became Director of Research of the Aluminum Castings Company of America. Later, step-by-step progress led to the high office of Vice-President of the General Electric Company in charge of the newly-organized chemical division, which office he now holds. Outstanding are his papers on "Metallography of Tungsten" and in conjunction with R. S. Archer as co-author, "Properties of Cold-Worked Metals," in which slip interference theory was developed. His and R. S. Archer's book, "The Science of Metals," is a recognized classic, used generally by metallurgists as a text book.

It affords me much pleasure to present Dr. Zay Jeffries of Cleveland, Ohio, for the Francis J. Clamer Medal, upon citation reading:

"For his meritorious contributions to the science of metals, which he has placed on a new and more intelligible basis."

MR. REDDING: Zay Jeffries, by power vested in me as President of The Franklin Institute, I hand you herewith the Francis J. Clamer Medal together with the Certificate and report which accompany it.

May we hear from Mr. E. W. Boehne.

MR. BOEHNE: The Louis Edward Levy Medal is awarded each year to the author of a paper of especial merit published in the JOURNAL OF THE FRANKLIN INSTITUTE, preference being given to one describing the author's experimental and theoretical researches in a subject of fundamental importance.

The use by the Germans of the V-1 and V-2 bombs of extraordinary range; the use of rockets, which give small ships the firing power of much larger ships; and the jet propelled airplane, whose speed is rapidly approaching that of sound—give special significance to the paper selected for this year's award, entitled "On the Reaction of Fluids and Fluid Jets," which appeared in the May, 1944 issue of the JOURNAL.

It is a mathematical analysis of the fundamental principles involved.

The paper is the work of Dr. Rupen Eksergian, and it is therefore proper to add that he is a member of our Committee on Science and the Arts and that an exception to the Committee's rule not to recommend awards to its own members has been made in his case, under special authority of the Board of Managers of the Institute, because of the outstanding character and timely importance of his paper.

Mr. President, it is my honor to present Rupen Eksergian to receive the Louis Edward Levy Medal, upon citation reading:

"For his paper 'On the Reaction of Fluids and Fluid Jets,' which appeared in the May, 1944 issue of the Journal of The Franklin Institute."

MR. REDDING: Rupen Eksergian, it gives me much pleasure to present to you, upon recommendation of our Committee on Science and the Arts, the Louis Edward Levy Medal, Certificate and report which accompany it.

I recognize Mr. W. Laurence LePage.

MR. LEPAGE: Mr. President: I present for a Franklin Institute award a man who has rendered great service by devices of his design to both war and peacetime training of aviators.

His trainers are in the form, roughly speaking, of the pilot's cockpit of an airplane, and are used on the ground for pre-flight training.

The cockpit is mechanically pivoted and mechanically arranged so that motions can be imparted to it which simulate motions and conditions of actual flight, and radio signals can be given by an instructor similar to radio signals received in flights.

The student aviator in the cockpit manipulates his controls accordingly for proper management of his plane under the conditions thus confronting him; and a recording device automatically records his simulated flight and discloses any errors, so that by further practice he can correct them.

Our Medalist invented his first device in 1927, while still a young man. It was so successful in saving time in flight training, that in the early 1930's he developed it into an instrument flight trainer, and later further developed it by adding the latest radio and navigation aids and aids for other crew members; and more recently an auxiliary superstructure for celestial navigation.

His devices have thus speeded the training of many thousand Army and Navy aviators and those of the other Allied Nations, and have doubtless saved many lives which would otherwise have been lost in training flights.

I present Edwin A. Link, of Binghamton, New York, for award of our Howard N. Potts Medal, upon citation reading:

"For valuable contributions in the field of training devices for aviators."

MR. REDDING: Edwin A. Link, I have the honor, as President of The Franklin Institute, to hand you herewith the Howard N. Potts Medal and Certificate, together with the copy of the report of our Committee on Science and the Arts.

The Chair recognizes Mr. Edward L. Forstall.

MR. FORSTALL: Mr. President: The Medalist I present graduated from the United States Naval Academy at a time when communication between vessels or vessels and shore was limited to whistles, flag signals and blinker lights.

The then infant radio telegraphy had made but slight progress in this field when he turned his attention to its development, and soon became the strongest advocate and leading authority on radio in the Navy.

This association with Navy radio began well before World War I and continued until his recent retirement—a lifetime of devoted interest.

In that period, due to his imagination, persistence and resourcefulness, and largely under his guidance, Navy radio developed from little more than a communications experiment to its present vital and indispensable role in operations of the fleet and its air arm.

In the words of a fellow officer, "The foundation and framework not only of Navy Radio but also of American Radio, as we know them today, are largely his work."

It is my privilege to present Rear Admiral Stanford C. Hooper, U. S. N. (Retired), of Washington, D. C., for an Elliott Cresson Medal, upon citation reading,

"In consideration of his pioneering leadership and practical utilization of discovery in the field of radio for the United States Navy."

MR. REDDING: Stanford C. Hooper, by virtue of the power vested in me as President of The Franklin Institute, I have the honor to present to you the Elliott Cresson Medal, together with the report and Certificate which accompany it.

Admiral Hooper briefly addressed the assembly, expressing publicly his thanks to his associates for the coöperation in his work which had terminated in this award.

MR. REDDING: The Chair recognizes Mr. Frank H. Rogers.

MR. ROGERS: Mr. President: The vast power developments which we have seen in recent years, such as the local developments on the Susquehanna River, those of the T.V.A. on the Tennessee River, Boulder Dam on the Colorado River and Grand Coulee Dam on the Columbia River, have been based on the use of hydraulic turbines.

Our Medalist has contributed largely to the development of such turbines.

As a leading Hydraulic Engineer, he has made a special study of the problems involved in the location of turbines to avoid pitting and unstable operation due to what is technically known as "cavitation."

His work has resulted in more than 90 patents, many of which are widely used in practice, and nearly 5,000,000 horsepower have been built embodying his design of discharge tube.

It is my pleasure to present Lewis Ferry Moody of Princeton, New Jersey, to receive the Elliott Cresson Medal, upon citation reading—

"In consideration of the leading part he has taken in the design and development of hydraulic turbines and pumps, the many patents issued to him, which have been widely used in practice, due to improvements in efficiencies, higher speeds and better operating characteristics, and his valuable contributions to the theory of design in this field of engineering."

MR. REDDING: Lewis Ferry Moody, by authority vested in me as President of The Franklin Institute, I hand you herewith the Elliott Cresson Medal together with a copy of the report and Certificate which accompany it.

The Chair recognizes Dr. Frederic Palmer, sponsor for the Franklin Medalist.

DR. PALMER: To account for the recurring change in luminosity of a certain group of stars known as Cepheid variables Dr. Shapley has proposed the ingenious theory that these are single stars which periodically expand and contract with an accompanying change in luminosity. The relationship between distance, luminosity, and period of these variables, as well as variables of other types, together with a similar relationship which he found to exist between distance, intrinsic brightness, and color, or spectral type, has provided him with a measuring rod for determining the distance and the dimensions of globular clusters, galaxies, and super-galaxies.

In addition he has contributed largely to our knowledge of eclipsing variables, the colors and magnitudes in stellar clusters, the dimensions of our own galaxy, the nature and distribution of external galaxies, the density of matter in space, and the structure of the universe.

All over the world he is known as a great scholar, investigator, and writer. In this country we know him as well as a great teacher, lecturer, and departmental executive.

Your keen eye, Sir, has penetrated the vast depths of space farther than that of any other man, and your lively imagination and your logical mind have enabled you to make sense out of what you saw.

Hence, Mr. President, it gives me pleasure to present, as a candidate for the award of a Franklin Medal, Harlow Shapley, Paine Professor of Astronomy, Harvard University,

"In consideration of his many valuable contributions to the science of Astronomy, and especially of his work in the measurement of the vast distances necessary for the determination of the nature and extent of our galaxy, as well as those of other galaxies external to ours."

MR. REDDING: Harlow Shapley, by virtue of the power vested in me as President of The Franklin Institute, I have the honor and the pleasure of presenting to you the Franklin Medal and Certificate, a Certificate of Honorary Membership in The Franklin Institute and a copy of the report of the findings of our Committee on Science and the Arts.

Dr. Shapley, having expressed his appreciation of the high honor bestowed upon him, then delivered a most interesting talk "On the Natural History of Globular Star Clusters."*

The program was concluded by the playing of "America" by Lieutenant Marriner, after which the meeting adjourned at 9:40 P.M.

* A short summary of Dr. Shapley's talk appears on page 419 of this issue. His lecture, in full, will appear in a forthcoming issue of the Journal.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, WEDNESDAY, MAY 23, 1945.*

After the playing of the National Anthem, the regular monthly meeting of The Franklin Institute was called to order by Mr. Charles S. Redding, President, who stated that this was the final meeting of the season. The next meeting will be in October.

Upon motion, duly seconded and carried, the minutes of the March meeting as published in the April JOURNAL were approved as printed.

In the absence of the Secretary, Dr. Henry Butler Allen, who is overseas on a special mission for the Chief of Ordnance, U. S. Army, the President called upon Dr. John Frazer Assistant Secretary of the Institute, who made the following report:

Increase in membership for the month of April:

Active	53
Associate	34
Student	16
Total	103
Total membership as of April 30, 1945	5,377

On behalf of Dr. Allen, Dr. Frazer expressed appreciation to the membership for its gratifying support of the Medal Day exercises, when four hundred and thirty members and friends attended.

The President then mentioned the fact that this is the second talk on the Charles Day Lecture Foundation and spoke briefly regarding that Foundation.

He then introduced Mr. Ralph E. Flanders, President on leave, Jones & Lamson Machine Company, and President, Federal Reserve Bank of Boston. He reminded the members and guests that, jointly with his brother, Mr. Flanders was awarded The Franklin Institute's Longstreth Medal in 1942, for a Thread Grinding Machine and Process. Mr. Flanders spoke on "Some Technical Developments of the War and Their Effects in Peace." This paper will be published in the August issue of the JOURNAL OF THE FRANKLIN INSTITUTE.

The meeting adjourned at 9:20 P.M., when the audience rose and extended a vote of thanks to the lecturer for a very interesting and informative talk.

JOHN FRAZER,
Assistant Secretary.

LIBRARY NOTES.

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 9 × 14 inches is thirty-five cents.

The library and reading room are open on Mondays, Tuesdays, Wednesdays, Fridays from nine o'clock A.M. until five o'clock P.M., Thursdays from two until ten o'clock P.M., Saturdays from nine o'clock until twelve noon.

* Stated monthly meeting, scheduled for third Wednesday, postponed one week, due to circumstances which made this change necessary.

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NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Abstract of **Starch Digestion by Vibrio cholerae in Strongly Aerated Media.**—ROBERT K. JENNINGS (*Journal of Bacteriology*, **49**: 163, 1945). Heavy crops of *Vibrio cholerae* may be obtained in liquid media containing starch as the source of energy for reproduction, without accumulation of acid by-products, *provided* that the culture is efficiently aerated. The failure to acidify starch media is at variance with the accepted report of the action of *V. cholerae* in such a substrate. When adequate aeration is provided it appears that the digestion of simple sugars outstrips the production of such nutrients by the saccharification of the dextrins derived from starch. Under these conditions the acid radicals derived from the sugar are in turn attacked and do not accumulate to acidify the culture. Digestion of the acetate and lactate radicals appears to be a highly aerobic process which does not take place to any great extent so long as glucose is available. Good growth may be obtained when sodium lactate is used as the energy food. Neither starch nor sodium lactate substrate is as satisfactory, however, as the previously described BRF medium for vaccine production.

BOOK REVIEWS.

AN INTRODUCTION TO ELECTRONICS, by Ralph G. Hudson. 97 pages, diagrams and illustrations, 14 × 22 cms. New York, Macmillan Company, 1945. Price $3.00.

With our increasing knowledge of electronics, its potentialities seem almost limitless. It is a science which has already found applications in many fields, such as medicine, geophysics, metallurgy, in addition to numerous branches of engineering. As a consequence the worker in those fields must know at least the basic fundamentals of electronics. This book aims to serve as such an introduction. Not just another popular book telling what electronics "can" or "may do," this emphasizes in addition the "how" and "why" of the subject.

The first chapter deals with the constitution of matter and introduces the fundamental particles, the electron, the proton and the neutron, explaining each and showing their relationship one to another. The existence of other (unstable) particles is mentioned briefly. Descriptions are given of various types of apparatus used as sources of high-energy particles, including the cyclotron and the Van de Graaff electrostatic generator. Since the flow of electricity varies under different conditions the author devotes a chapter to conduction in gases, in nonmetallic liquids, in solids and in a vacuum.

The remainder of the volume treats of the practical applications of electronics in radio communication, reproduction of sound and pictures, modern sources of light such as the fluorescent and mercury-vapor lamps, and various types of rectifiers for converting alternating current to direct current. A concluding chapter touches more briefly on some of the newer developments—the electron microscope, radio compass and radiosonde.

There are many excellent full page photographs as well as numerous diagrams which add to the value of the book. Although the presentation has been made without recourse to mathematical theory, much that is complex has been included, necessitating thoughtful reading. It should prove a satisfying book for the reading audience for whom it is intended.

G. E. PETTENGILL.

MECHANICAL AND ELECTRICAL EQUIPMENT FOR BUILDINGS, by Charles M. Gay and Charles deV. Fawcett. (Second Edition.) 453 pages, tables and illustrations, 14 × 22 cms. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Ltd., 1945. Price $5.00.

This is a technical book on the basic theories and applications concerned with building equipment. It is a text book of building equipment. In this second edition some of the chapters are rewritten so that theories are simplified, tables revised and modernized, and new data added.

Water supply, its sources, equipment, and design of systems are amply covered. Under the section on Plumbing and Drainage, installations, equipment, and private sewage disposal are presented. In order named, heat losses, heating systems, and air conditioning are fully discussed. Not only is the problem of wiring and lighting, its materials, methods of installation, and fixtures considered, but also electrical machinery, including elevators and escalators. The chapter on acoustics is a practical approach to this important phase of building equipment.

Each chapter is well illustrated. Tables and charts are used to explain the text. Throughout the book, problems are stated with their solutions. At the end of each chapter there are problems for the reader to answer.

D. S. COLLINS.

THE BUILDERS OF THE BRIDGE, The Story of John Roebling and His Son, by D. B. Steinman. 457 pages, plates, 14 × 21 cms. New York, Harcourt, Brace and Company, 1945. Price $3.50.

The lives and works of great engineers and industrialists is as much a part of history as the usual and more publicized achievements of others, for theirs is a work of peace, of lasting

contributions to the welfare of mankind, of utilization of new knowledge, and of pioneering in new fields. John Roebling and his son were men of this class and they are men who should be better known to us all and the book at hand endeavors to do this.

The story reveals that John Roebling, the youngest of five children, was born of parents of modest means in Mühlhausen in Thuringia in 1806. Early in life he exhibited brilliance and hunger for knowledge and later, through the sacrifices and frugality of his Mother, he attended the Royal Polytechnic Institute in Berlin, then the foremost engineering school in the world. At twenty he began his professional career and had ideas of his own. He wanted to be a builder of great bridges but found that opportunities in Germany for a young engineer were very limited. He served his apprenticeship, however; then turned to seek an avenue of escape from a routine that became oppressive. He finally organized a colonizing party for America, which subsequently settled in Pennsylvania. It was not long before Roebling saw here the need for canals, bridges and railroads. He conceived a new method of building wire cables—the "air-spinning method"—and was given opportunity of applying it on the structure to carry the Pennsylvania Canal across the Allegheny River at Pittsburgh. With this his career as a bridge builder began. He built a span across Niagara to carry railroad trains and after many years of heart-breaking strain he completed his great Ohio River bridge at Cincinnati. Finally came the opportunity to build his dream span, the Brooklyn Bridge. Working feverishly, he completed his plans, and then, within sight of his goal, a construction accident ended his life. His soldier son, whom he had trained to be his successor, carried the task forward, working with his men under the river, until he fell victim to the dreaded caisson disease. Bedridden, he continued to direct the work from his Brooklyn home overlooking the bridge. In 1883 with the opening of the span, the world applauded the creation of the poem in granite and steel that is the Brooklyn Bridge.

The author of the book is a bridge engineer who has made an exhaustive search and study of a vast amount of material—original papers, manuscript letters, periodical literature, books, etc., in order to write this book. The book itself stands for the efficiency of classification, the logical arrangement, and the ingenious and interesting presentation of this material. It is easy to read and instructive.

R. H. OPPERMANN.

PHOTOGRAPHIC ENLARGING, by Franklin I. Jordan. 252 pages, illustrations, 19 × 25 cms. Boston, American Photographic Publishing Co., 1945. Price $3.50.

Photography is a scientific subject which has been made available to a host of non-scientific enthusiasts. It is among the foremost examples of what may be done through methods of clear-cut, simple explanations, and this undoubtedly has been a leading factor in the widespread production of pictures, the quality of which was not thought possible 15 to 20 years ago.

This book has been written to help photographers make better enlargements. It is addressed primarily to those thousands of amateurs who annually turn out a great grist of art and beauty, although working for the most part under improvised conditions in their homes. The general scheme of presentation is the reviewing of the process of making an enlargement and the offering of suggestions for improvement. It starts with a discussion on enlargers which extends into other equipment, and it is here that the reader can see a value of the work that is continuous. The author is very frank that some equipment is not necessary, and some is only occasionally used. The next topic is the negative, what it should and should not have, and it includes retouching and the use of New Coccine. The chapter on enlarging paper is very clarifying and should help many who are bewildered on the many kinds of paper available.

After this background on the negative and paper the actual work of enlarging is taken up, beginning with the exposure. Here focusing, the use of stops, measuring the light, handling the paper, etc., are all given attention. A discussion on development precedes fixing, washing, drying, spotting and after processes. The latter part of the book is devoted to such subjects as tricks and dodges to manipulate photographic processes to make photos more widely useful,

and combination printing such as printing in clouds. The Bromoil process is described, in which the artistic ability of the worker plays a big part.

The book is of that class which has made photography so popular. It is a clear-cut, well done presentation by a master photographer and teacher.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

The Chemical Process Industries, by R. Norris Shreve. 957 pages, tables, drawings and illustrations, 15 × 23 cms. New York, McGraw-Hill Book Co., Inc., 1945. Price $7.50.

Careers in Science, by Philip Pollack. 222 pages, illustrations, 14 × 21 cms. New York, E. P. Dutton & Company, Inc., 1945. Price $2.75.

The Chemistry of Acetylene, by Julius A. Nieuwland and Richard R. Vogt. 219 pages 15 × 24 cms. New York, Reinhold Publishing Corporation, 1945. Price $4.00.

Ebulliometric Measurements, by W. Swietoslawski. 228 pages, tables and illustrations, 16 × 23 cms. New York, Reinhold Publishing Corporation, 1945. Price $4.00.

CURRENT TOPICS.

ARMY AND NAVY NOTES.

Electrons Photograph Spark Flashes Going 5,000 Miles an Hour.—A stream of electrons, driven in a pencil-thin beam, are photographing electrical sparks that flash in front of them at more than 5,000 miles an hour, it was reported recently.

Stopping the speeding spark flashes at one-tenth of a millionth of a second, the electronic beam is recording airplane engine ignition actions to help solve the problems encountered in producing faster and more powerful warplane motors, according to E. W. Beck, lightning arrester engineer for the Westinghouse Electric and Manufacturing Company.

The electronic device which guides the electrons in their new task is the streamlined Westinghouse cathode ray oscillograph—once exclusively a laboratory tool—but now built on an assembly line basis for use on the production lines of the nation's war plants. Among war plants now using it are the Scintilla Division of Bendix, and the Bosch Company.

The new electronic oscillograph is giving aircraft engine men more data about the ignition systems of high powered airplane engines than has ever existed before. The unit daily answers tough problems—solving them as would no other known device and with a rapidity and accuracy that has astounded veteran motor engineers. In fact, the electronic oscillograph has opened new fields in research.

Mr. Beck gave this description of its operation:

Functionally, it takes pictures on the household variety of camera film and makes its impressions in much the same manner as an x-ray.

The beam of electrons is created by a high voltage rectifier. These electrons are guided into their narrow path by magnetic fields and by a series of plates which channel them downward. To prevent the beam from registering on the film before the ignition study is made, the device incorporates a beam trap that deflects the electrons out of the photographic channel.

The electrical impulses which are to be studied are shot across the path of the electronic beam just above the film rack. The impulses force the electronic beam out of its straight path and cause it to "write" on the strip of photographic film a record of the voltage. Simultaneously, the electron pencil records the time involved to give engineers a graphic record of electrical events that occur in periods as short as one hundred-millionth of a second.

The fastest speeds, Mr. Beck explained, are photographed on a stationary film strip, but slower speeds of less than eight millionths of a second are recorded on a revolving drum that turns 7,000 times a minute.

"The rotating film drum is necessary for certain uses," he added, "because fixed film will not register 'long' times like a fiftieth of a second. Recordings on the drum reveal the most minute electrical phenomena."

He added:

"Our research engineers collaborated with warplane engine manufacturers in testing ignition systems with the oscillograph and the results pointed the

way to better engines. Immediately improvements were made and fighting ships once grounded because of ignition trouble are now in the skies helping to bring home victory."

In peacetimes, the cathode ray oscillograph and its pencil-thin beam of electrons will play an important part in the study of transmission line faults, insulation and electrical equipment design and the effect of lightning on power systems, Mr. Beck said.

R. H. O.

Save Saw Waste of Spruce.—Sitka spruce—the airplane lumber—that used to be wasted in sawdust can now do its share of flying as a result of experiments in veneer cutting and gluing in which the Forest Products Laboratory cooperated with spruce producers, a Forest Service report explains.

Sitka spruce of first quality is preferred for use in airplanes because of its strength and light weight. Rigid inspection rejects all but the most perfect timber, and it is difficult to obtain enough to meet war demands. Plane builders have used both sawed lumber and glued laminated members built up from thin pieces sawed from spruce timber. In either case, in cutting timber into usable sizes, saws waste precious wood in the form of sawdust.

An alternate way of producing thin stock is to rotate the log on a machine resembling a lathe, with a long and sharp knife paring off a sheet of veneer about one-seventh of an inch thick. By this method there is no sawdust waste.

Experiments just reported show that these rotary-cut veneers can be glued together under pressure with one of the new urea-resin glues, and that the product is equivalent in strength to either the solid wood or the laminated products built up from sawed pieces. Because of the weight of the glue and the slight compression of the wood in the press, the cut-veneer laminated members are slightly—about seven per cent.—heavier than solid wood. But the new product is as strong and serviceable as solid wood.

When spruce suitable for airplanes is scarce, the saving in sawdust waste which this method makes practical, is regarded as important by lumber specialists for the airplane industry. In laminated members made from thin sawed pieces, it often happens that the sawdust amounts to as much as the wood remaining. Even in solid lumber the sawdust percentage is a substantial loss.

R. H. O.

Construction Records Made by Signal Corps in Italian Advance.—(*Electrical Engineering*, Vol. 63, No. 10.) New records for the rapid extension of open-wire circuits were set by the communications men of the Signal Corps during the Fifth Army advance in Italy in May and June.

From the night of May 11, 1944, when the Allied offensive was launched until the end of May, the pole line carrying the main Army open-wire axis was stretched to Terracina, a point 60 miles from the break-through point by construction elements for six Signal Corps battalions. One construction company was sent to the Anzio beachhead and worked back along the highway to meet the anticipated advance of the teams pushing north from Terracina. In addition to the main axis construction, two open-wire circuits were constructed

to provide for the French Corps at Ausonia and two more for a lateral to the British Eighth Army. Work also was commenced on another lateral of two circuits to the Eighth Army.

In June the Signal Corps exceeded even these feats by extending the open-wire circuits a distance of 140 miles. So rapid was the advance of the troops that all available construction personnel of four Signal battalions, augmented by two construction companies, worked at top speed at the task.

Army depots issued, during the month of May, three times the amount of field and assault wire issued during the earlier static period of the war; and in June they issued the impressive totals of 19,500 miles of field wire W110, 5,000 miles of assault wire W130 and 1,500 miles of spiral 4 wire.

Radio circuits and radio teletype service kept pace in performance with the open-wire circuits, but the pigeon service experienced an "encouraging difficulty." May was a big month for the pigeoneers, with 28 combat lofts out on tactical assignments operating from 15 widely distributed front-line locations, and with an average of about 60 messages carried by the birds daily; but in June the front advanced so fast that it was impossible to settle the lofts quickly enough to serve the various Command Posts before a new advance. However, the same speed of advance which prevented the settling of the pigeon lofts prevented the establishment of wire communications to all hospitals, and the pigeons were a satisfactory means of communication for the Medical Corps in sending its daily reports back to Army Headquarters from forward installations.

R. H. O.

Industrial X-Ray Inspects Cable.—(*Electrical World*, Vol. 122, No. 16.) Industrial x-ray testing is successfully used by the General Cable Co. to make continuous visual inspection of the insulation and core of its cables and to make photographic x-ray analysis of cable construction.

For example, a complex problem of design was recently encountered in connection with the development of some special multi-conductor cables for a service condition requiring repeated twisting or torsion. Conventional methods of stranding and cabling to obtain that flexibility had not given the desired performance characteristics. Therefore a number of new and different core designs were made up into finished cables and subjected to twisting and x-ray tests. This instrument proved to be a valuable guide, since by showing the movement and its effect on the various specimens, it determined the correct design.

Further practical applications have been made in investigations of broken conductor, eccentricity of insulations or coverings and of internal causes of electrical breakdown, such as air voids or foreign particles. Other important uses will undoubtedly be found, but already the x-ray has proved to be a valuable guide in effecting technical improvements in the manufacture and testing of wire and cable.

R. H. O.

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